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The Walleye Pollock

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On the cover:
The walleye pollock,
Theragra chalcogramma.

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The Origins of New Zealand's Chinook Salmon, *Oncorhynchus tshawytscha*

ROBERT M. McDOWALL

Introduction

New Zealand's acclimatized stocks of anadromous chinook salmon, *Oncorhynchus tshawytscha*, are one of very few unequivocally successful transplants of any anadromous Pacific salmon, and the only one of long standing (Childerhose and Trim, 1979). This lack of success is in spite of attempts to establish various salmon species in many areas, that date back to the era when salmonids were being shipped to many and diverse parts of the world prior to about the 1930's, including such unlikely places as Brazil, Hawaii, Mexico, and Nicaragua (McDowall, 1988). Early attempts to establish anadromous pink and coho salmon, *O. gorbuscha* and *O. kisutch*, respectively, in northeastern North America seem ultimately to have failed, despite initial signs of success (Lear, 1980). Pink salmon, transplanted to western Arctic Russia, spread further into Scandinavia, but were only briefly successful there (Berg, 1977; Bakshtansky, 1980). Transplants of various species of *Oncorhynchus* to Chile generated some adult returns from smolts released to sea, though these do not seem to have persisted (Zamorano, 1991). By comparison, the New Zealand situation is quite unequivocal and of long-standing clarity: Chinook salmon have been established as self-supporting, anadromous populations, primarily in rivers along the east coast of New Zealand's South Island, since about 1905 (McDowall, 1990; Fig. 1).

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ABSTRACT—Chinook salmon, Oncorhynchus tshawytscha, *are well established as anadromous and landlocked runs in New Zealand. Ova introductions during the 1870's (probably from the McCloud River, California, U.S.A.), failed to generate anadromous stocks, but further introductions of fall-run salmon ova from hatcheries in California's Sacramento River basin in the early 1900's were successful and formed the basis for existing runs. The first batch of ova in the 1900's consignments originated from Battle Creek, a Sacramento River tributary, but the explicit source of later batches is not known. It seems likely that the successful runs stem from the second batch (1903 brood year—1904 consignment in New Zealand), probably augmented by returns from later importations.*

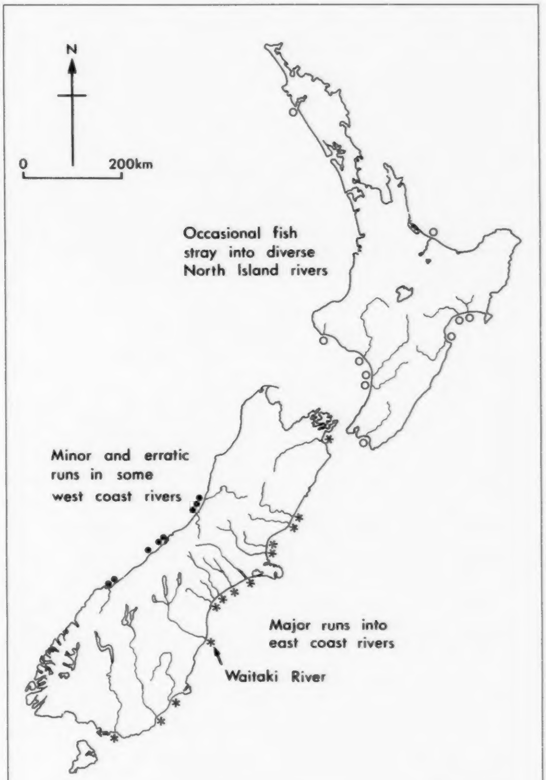

Figure 1. — Distribution of anadromous chinook salmon in New Zealand, showing broad presence along the east coast of the South Island, intermittent and minor runs on the west coast, and occasional stragglers appearing more widely throughout New Zealand.

New Zealand is widely known for its stocks of acclimatized salmonids, especially of brown trout, *Salmo trutta*, and rainbow trout, *O. mykiss*; less well known are its acclimatized stocks of Atlantic salmon, *Salmo salar*; brook char, *Salvelinus fontinalis*; lake trout, *S. namaycush*; and sockeye salmon, *O. nerka* (McDowall, 1990). The origins of stocks of these species have been of considerable interest and confusion—interest stimulated by a concern to understand the stock origins of the populations, and confusion generated by poor record keeping when the fish were transported around the globe between the 1860's and early 1900's. The origins of New Zealand's rainbow trout were clarified by Scott et al. (1978) and of the sockeye by Hardy (1983) and Scott (1984). However, the source of New Zealand's chinook salmon has not been reviewed since the fish were established in New Zealand in the early 1900's, and their explicit source remains a matter for speculation.

Questions relating to genetic and phenotypic differences among stocks of Pacific coast salmonids have generated much research interest in recent years. This is due partly to extensive hatchery releases, made either for enhancement or regeneration of heavily exploited anadromous salmonid runs, or to restore those damaged by habitat deterioration and river impoundment. There have also been widespread and massive releases to support recreational salmonid fisheries. In addition, there has been active interest in the evolution of Pacific salmon species and stocks.

Considerable concern has grown about these various hatchery releases. Often the fish are of different (and even unknown) genetic provenance from those already present in the receiving ecosystems, and sometimes they are of reduced genetic diversity as a result of many generations of hatchery rearing. There is legitimate concern that these hatchery introductions might disrupt fish stocks finely adapted to local habitat characteristics; there is concern to protect the genetic integrity of locally adapted stocks, sometimes recognized as local subspecies of more widely distributed polytypic species (Allendorf and Leary, 1988; Behnke, 1992; Hilborn, 1992).

"Wild" trout and salmon have become something of a "clarion call" among those sensitized to the issue of protecting local stocks (White, 1992). This same concern is relevant to New Zealand's stocks of chinook. For many decades after their early 1900's establishment they were not interfered with, and hatchery releases into the rivers were minimal; however, with the development of enhancement technologies in western North America and the prospect of ocean ranching both for commercial purposes and to enhance recreational angling in New Zealand, extensive hatchery releases and transfers between catchments were undertaken during the 1970's and 1980's (McDowall, 1990). The concerns that apply to stocks in North America therefore have similar implications for the management of New Zealand's acclimatized chinook stocks. Even though these have not had millions of years of local selection to adapt them to the different conditions found in New Zealand rivers (as is true in North America), there is nevertheless evidence to suggest that fundamental life history parameters such as age and size at maturity, spawning season, and relative fecundity, differ among New Zealand river systems (Quinn and Unwin, 1993).

Among certain stocks at risk in North America have been the diverse chinook salmon stocks of the Pacific coast (McDonald, 1981; Nehlsen et al., 1991); because of the fragility of some of these stocks, the presence of acclimatized chinook salmon in New Zealand is of wider interest and their stock origins in North America of particular interest. In addition, the presence of these stocks in New Zealand for about 90 years provides a valuable opportunity to examine changes in allele frequencies during that period of isolation. For this reason alone, identification of the origins of New Zealand chinook stocks would be of interest. In particular, the stocks on the Sacramento River (Rutter, 1902) suffered severely from the construction of the Shasta Dam in 1943, which prevented salmon from reaching the many spawning tributaries in the upper river, including Mill Creek, the McCloud River, and other waters where chinook salmon stocks spawned (Cope and Slater, 1957). These were waters where racks and hatcheries had operated in earlier years to provide salmon ova for release in many other areas, including New Zealand.

Early New Zealand Chinook Salmon Introductions

Initial introductions of chinook salmon to New Zealand took place in the 1870's. In 1875 the Hawkes Bay Acclimatisation Society obtained ova "through Dr. Spencer F. Baird, Chairman of the United States Fishery Commission" (Thomson, 1922). The ova, though originally destined for the town of Napier, began to hatch as they reached Auckland, and they were released into nearby rivers; none reached Napier. Further consignments were sent in 1876, 1877, and 1878, but contemporary New Zealand accounts do not state their explicit origins; the common assumption has been that they came from the Baird Hatchery on California's McCloud River, a tributary of the Sacramento.

A history of California salmon hatcheries suggests that, at this early period, the Baird Hatchery was the only one in a position to provide ova for New Zealand (Leitritz, 1970). Their source is largely of academic interest, anyway. There is only slim evidence that even an occasional salmon from the 1870's releases may have returned to New Zealand rivers as adults, e.g. a few rather modest–sized fish, thought by some to be chinook salmon, were taken from rivers like the Waimakariri (3.6, 2.4, and 2.0 kg) and Waitaki (4.4 kg; Thomson, 1922), but there is as much likelihood that they were sea–run brown trout which abounded in such rivers and grew to this or greater size.

One early report claimed that a fish from a New Zealand river (1884) was identified as a California salmon by T. H. Bean, of the U.S. National Museum (N.Z. Marine Department, 1885) Unfortunately, this fish is no longer in the collections of the Museum. Thomson (1922) related several events reputed to involve specimens of *Oncorhynchus*

from New Zealand rivers. L. F. Ayson, who was responsible for the later, successful introductions of chinook salmon, and who was New Zealand's Chief Inspector of Fisheries from 1898, wrote that "apparently some fish caught in the Waitaki River have been identified as belonging to the Pacific Salmons or *Oncorhynchus* family," but he thought the evidence "far from compelling" (N.Z. Marine Department, 1899).

Whether or not any of these fish were chinook remains uncertain, and in terms of the present stocks of chinook salmon in New Zealand it is probably unimportant. What is very clear is that if chinook were still present in New Zealand by 1900, as a result of the 1870's importations, they were sparse indeed. Such runs, if any, were most likely restricted to rivers of Canterbury where stocks of chinook are now present, since there were never even hints of consistent runs in any other New Zealand rivers before 1900, nor have there been since, apart from some sparse and intermittent runs on the South Island's west coast (Fig. 1). There were certainly no fish running into any of these rivers in the late 1800's in numbers comparable with those that followed the early 1900's releases, and it can be concluded that even if there were a few salmon in these rivers, their genetic contribution to the stocks that developed rapidly in the early 1900's was probably minor.

Most commentators have considered the 1870's releases a failure. Certainly, the attitude of L. F. Ayson, who had major involvement in the early 1900's chinook releases, gave no support for any significant success following the 1870's releases. He obviously saw some glimmers of success in 1899, but he also proposed a series of further major importations, and probably would not have done so had he thought there were significant existing runs. Somewhat later he was even more definite and negative, thinking that "had any of these prolific fish survived from the spasmodic efforts to acclimatize them previous to 1900, they would have disclosed themselves long before the . . . importations in 1900" (N.Z. Marine Department, 1917). Thus, Ayson, on the basis of his contemporary knowledge and experience, clearly thought that these 1870's introductions were probably a failure.

Ayson visited North America in 1899 and returned with offers of salmon ova, noting that supplies could be obtained from the Baird and Battle Creek Hatcheries and Canada's Fraser River; from his detailed description, it is clear that he visited Battle Creek, but apparently not Baird Hatchery (N.Z. Marine Department, 1899). When he returned to New Zealand, Ayson recommended that the American offer should be accepted, and he successfully promoted further major and repeated importations of Pacific salmon ova. The New Zealand Government approved construction of a hatchery on the Hakataramea River, a tributary of the Waitaki (Fig. 2).

The 1870's consignments of salmon ova to New Zealand, which were of spring–run stock (those that enter rivers from the sea during spring), had been liberated in small batches in many rivers. Ayson was critical of this practice and intended concentrating the forthcoming releases on one river system. He chose the Waitaki River partly because of its resemblance to western North American salmon rivers—and he knew the Waitaki well, having worked there earlier in his life. It was also partly because he surmised that north–flowing ocean currents sweeping past the Waitaki River mouth would disperse the fish northwards, and help to establish runs in other South Island rivers north of the Waitaki. And so it soon proved.

Records of Early 1900's Importations

New Zealand records of how many consignments of chinook came to New Zealand are inconsistent, some listing four, others five. The New Zealand Marine Department, the agency responsible for the importations (1901–07), recorded that five consignments of chinook salmon ova were shipped, the available details being as follows (North American brood years are the previous year in all instances):

1) 1901–500,000 ova, arrived in New Zealand in early January;
2) 1904–300,000 ova, arrived in January; accompanied by G. H. Lambson;
3) 1905–300,000 ova, arrival date not given; accompanied by L. F. Ayson;
4) 1906–500,000 ova, arrival date not given; accompanied by L.F. Ayson;
5) 1907–500,000 ova, left the United States 8 February, arrived in New Zealand late February; accompanied by L. F. Ayson (N.Z. Marine Department, 1901–08)

These Marine Department records are consistent with data on ova handled by California hatcheries of the U.S. Fish

Figure 2. — The Hakataramea hatchery (probably ca. 1920's), built in the early 1900's to support the chinook salmon introduction program; it remained in operation until 1942.

Commission for the brood years 1900–06 (U.S. Commission of Fish and Fisheries, 1902, 1903; U.S. Bureau of Fisheries, 1904–07); Ayson (1910), in his slightly later review, also listed five consignments. However, Thomson (1922), in his very detailed, and usually authoritative, historical account of animal introductions to New Zealand, listed only four batches, omitting that which arrived in New Zealand in 1905; this account has wide acceptance. Perhaps coincidentally, noted U.S. ichthyologist Charles Gilbert, in a letter[1] to C. A. Vogelsang of the California Department of Fish and Game (12 March 1910) also wrote of just four consignments. It appears that both Thomson and Gilbert were wrong.

No totally contemporary publications in New Zealand state where any of these ova came from, apart from "United States"; however, Ayson (1910) shortly thereafter stated that the 1901 ova "were supplied by the United States Bureau of Fisheries, from its station at Baird, California, on the McCloud River [and] came over in charge of Mr G. H. Lambson, superintendent of the Baird Station." However, the latter source was not recorded in the initial account of the importation (N.Z. Marine Department, 1901), an account which Ayson, himself, probably wrote.

Ayson's (1910) statement that the 1901 batch came from Baird Hatchery is not as unambiguous as it seems, because ova were often shifted between the hatcheries on tributaries of the Sacramento River (Baird, Battle Creek, Mill Creek, etc.). In this regard, records of 1900 brood year ova handled by Battle Creek are quite explicit, stating that "3,079,660 [ova] were transferred to the Sisson hatchery of the California Commission and to Baird station, including 500,000 sent to New Zealand." The 1901 consignment, thus definitely came originally from Battle Creek not Baird, and were from fall–run fish, as it was found impossible to get summer run chinook from Battle Creek, owing to its high water temperatures at that season (U.S. Commission of Fish and Fisheries, 1902). This is the last year in which details of the source of ova were published by the Commission, and records of ova shipped from the Baird Station were largely lost in a fire at Baird in 1909. Consequently, there are apparently no surviving details of the explicit source of the four later New Zealand consignments, though they are likely to have come from the various hatcheries in the Sacramento River basin.

Returns From the Early 1900's Releases

The first indication of the return of chinook salmon to New Zealand waters from the early 20th century releases was a report that "fish believed to be salmon have been caught at the mouth of the Waitaki River" (N.Z. Marine Department, 1905). In a report dated 9 December 1905, James Hector, a noted New Zealand naturalist, reported that a fish sent to him was "without doubt a young specimen of the genus *Oncorhynchus*" (N.Z. Marine Department, 1905), but it is not possible to determine from Hector's account whether this fish was from a return in the "1905" run or a very early return from the "1906" run; either is possible.

It is probably not important. The fish itself, which Hector thought a "young specimen," was only 522 mm long, and of particular note had "rudimentary testes." Since 448 4-year-old chinook salmon had been reared at and released from the Hakataramea hatchery during 1904–05 (Thomson, 1922), the fish Hector examined was probably one of these. Fish of this small size with rudimentary testes certainly do not feature in the present chinook salmon runs in New Zealand rivers. Small "jacks" of this size are common enough in the runs, but are sexually mature, typically with well–developed testes. Given the hatchery rearing of fish to 4 years old before release, and the rudimentary state of the testes of this fish, it may never have been to sea. Nothing more conclusive can be drawn from this report of returns in 1905. Whether any truly sea–run fish were caught in 1905 is not known; any would have been from the 1901 consignment.

Charles Ayson, son of L. F. Ayson, also worked on the Waitaki salmon run, and at the Government's Hakataramea Hatchery, eventually assuming control of it. He may have been familiar with this early history. In a report evidently written in 1958, Charles Ayson (1959) asserted that the first fish to come back from the sea weighed 5.5 kg and was taken in the Hakataramea trap in May 1905. At this time it would have been 4.5 years old, if derived from the original 1901 release. However, dating this return was clearly controversial at the time, as Ayson (1959) added that: "Different dates have been given . . . as to the year of the first returned fish, but . . . 1905 is definitely correct." This 1959 account of events in 1905 differs from others, including some that were much more contemporary (N.Z. Marine Department, 1906; Ayson, 1910; Thomson, 1922). Further, in the same 1959 report Ayson stated that in the early 1900's "probably five million salmon eggs were imported," and this figure, too differs greatly from other reports (mostly 2.1 million ova, though Davidson and Hutchings (1938) reported 1.6 million). This discrepancy casts further doubt on the accuracy of Charles Ayson's account, which seems to be based entirely on memory, and was written 50 years after the event by an elderly man.

L. F. Ayson reported numerous fish caught by anglers during the 1906 season (N.Z. Marine Department, 1907), and Hector was again sent specimens for study. One was a ripe female of 7.3 kg, and then three more fish, a male 635 mm and 2.7 kg (spent), a female 559 mm and 2 kg (spent), and a male 432 mm and 0.7 kg (ripe). Hector considered that the two larger of this trio of fish were 4-year-olds and the smaller one a 3-year-old; if these ages were correct, these fish were only a fraction of the size of chinook salmon of these ages in modern runs in New Zealand (Flain, 1982; McDowall, 1990), and it implies that they, too, may have been hatchery–reared for some time before release; they, too, may never have been to sea, or have done so only briefly before returning to the Waitaki River—scarcely evidence of the foundations of an anadromous salmon run.

The 7.3 kg fish therefore assumes greater significance. Judging by current

[1] Letter in possession of Mark R. Jennings, 1830 Sharon Ave., Davis, Calif. 95616.

growth rates of chinook in New Zealand (Flain, 1982; Quinn and Unwin, 1993), a 7.3 kg fish would be either 3 or 4 years old. This fish is therefore probably the first captured chinook salmon that went to sea and returned as a mature, prespawning adult. There were evidently others in the river that year, as there were newspaper reports of a few salmon spawning in the Hakataramea River at that time, April–May (fall–winter) 1906.

During 1907 there was a modest run of salmon into the Waitaki. Though most of the run was over before the rivers were inspected, 30,000 ova were obtained from fish in the 1907 run into the Hakataramea (N.Z. Marine Department, 1908), and Ayson (1910) wrote later of "quite a run of salmon up the Waitaki River [which] spawned in several of its main tributary rivers. In the Hakataramea between 300 and 400 salmon had spawned naturally in the 3 kilometres of river before it joins the Waitaki." A similar run was reported in 1908, though the fish were "on average . . . considerably heavier." These events confirm the initiation of a run in 1906–07 of chinook salmon into the Waitaki that resulted from the 1901–07 releases, and which became the progenitor of runs into other rivers along the east coast of New Zealand's South Island.

In a few years, salmon spread naturally north along the coast of the South Island, just as L. F. Ayson had hoped, establishing anadromous runs in the Rangitata, Opihi, Ashburton, Rakaia, Waimakariri, Hurunui, and Waiau Rivers; these runs persist today (McDowall, 1990) (Fig. 1).

The Source of the New Zealand Chinook Salmon Runs

Several questions surround the origin of the fish that did return to New Zealand rivers from about 1906 onwards:

1) Which release did they originate from?
2) What river did the original stock come from?
3) How do the New Zealand runs compare with the source stocks with regard to their seasonal occurrence and age structure?

Though it might seem that the primary question to discuss would be the second of those listed above, identification of the source population depends on establishing which New Zealand releases produced the returns.

As noted above, the key fish in all this discussion appears to be the 7.3 kg fish examined by Hector in June 1906 since this was the first almost certainly anadromous salmon known to have returned, and was presumably representative of the first "run" from the early 1900's introductions. This fish could have been derived from the 1901 (1900 California brood year) importation, in which case it would have been about 5.5 years old. Or it could have been from the 1904 (1903 brood year) importation, which would have made it about 2.5 years old. Ayson's comment that the more abundant fish that returned in 1907 were larger may suggest that these were from the same brood year as the 1906 return, but a year older, i.e. fish that were "considerably heavier" than 7.3 kg and either 6.5 or 3.5 years old. There is no way of being certain which of these ages is correct, but it seems probable, on the basis of the ages and sizes of chinook salmon that now return to New Zealand rivers (Flain, 1982; Quinn and Unwin, 1993), and in the apparent absence of runs into the Waitaki/Hakataramea Rivers in 1903, 1904, and 1905, that the lower age is correct-that there was a small return of a few fish in 1906, probably including the 7.3 kg fish, 2.5 years old, and from the 1904 release, rather than 5.5 years old and from the 1901 release. If that is so, the more abundant, larger fish reported in 1907 could have been 3.5 years old, also from that 1904 release, quite probably with some smaller, 2.5 year old fish from the 1905 releases.

With the knowledge of some natural spawning by additional fish returning in 1906, observed natural spawning from the 1907 returns to the Waitaki, plus additional importations and releases of California stocks in 1906 and 1907, it is obvious that there is no way of distinguishing the sources of any returns after 1907, whether from natural reproduction, or from one or other of the releases derived from imported ova.

There is no hint of any salmon returning in 1902, 1903, or 1904, so the likelihood of a return of fish from the 1901 release seems slim; an unobserved run into a small river like the Hakataramea (3.5 m^3/second median flow) seems unlikely, with workers busy on the river rearing salmon at the hatchery and with keen anticipation of a return of fish from earlier releases. With releases made from the production of a consignment of 500,000 ova, returns from this batch could have been prolific. Although there will never be any certainty, this fragmentary evidence leaves us with the probability that the first returns were from the 1904 release, and that this release, either alone, or probably with augmentation from the 1906 and 1907 releases, formed the source of New Zealand's chinook salmon runs. Because the origin of the 1904, 1906, and 1907 importations is not explicitly documented, all that can be said is that they came from the Sacramento River drainage system.

As L. F. Ayson (Fig. 3) recounted, initial returns to New Zealand rivers took place in the autumn and early winter, equating with a fall run of chinook salmon in California. This return timing could have occurred because the parent stock in California were fall–run fish, or it could have been because the fish were ready to return to fresh water after 2.5 or 3.5 years at sea, as they would have been if they were spring–run fish. If maturation in chinook salmon is triggered by changes in day length, the former scenario is more likely.

Records of the ova taken at the various hatcheries on the Sacramento River indicate that the ova sent to New Zealand in the period 1901–07 were fall run fish. New Zealand runs, today, are also chiefly in the fall: Some fish begin to return to rivers from November (mid–spring) onwards, continuing through December and early January (summer). However, these early immigrants form a continuum with the main run, which builds up from late January and through February and March (fall), with spawning occurring from April until June (McDowall, 1990; Quinn and Unwin, 1993). No studies have yet been under-

Figure 3. — Lake Ayson (right), as an elderly man, shown with two assistants, holding adult chinook salmon taken at a trap in the upper reaches of the Waitaki River.

taken to determine whether the early, November–December (spring) fish in any way comprise a stock distinct from the main run of fish in February–March. On the face of it, New Zealand seems to have a "fall run" of chinook salmon, like those from which it was derived.

The age structure of the runs in most New Zealand rivers is as follows: Three-year-olds predominate in any brood year; 4-year-olds may be second in abundance, but sometimes 2-year-olds are more common; there are very few 5-year-olds, and no 6-year-olds or older (Flain, 1982). Pack and Jellyman (1988) recorded salmon up to 6 years old in the Clutha River, but these fish had reared for several years in inland lakes before emigrating to sea. Quinn and Unwin (1993) concluded that the New Zealand stocks of chinook grow more rapidly than the American counterparts, up to an age of 3–4 years, but mature earlier; earlier maturation may be a result of this more rapid early growth.

In this regard the New Zealand stocks differ from those in California, in which 4-year-olds predominate, with some fish 6 years or even older (Gilbert, 1914; Flain, 1982). The younger age structure in New Zealand dates back at least as early as the 1920's, as scale samples sent to Charles Gilbert, the noted early 1900's American fisheries biologist, were aged and showed that the New Zealand fish were already returning at a younger age than those from which they were derived in California (N.Z. Marine Department, 1927). Further scale samples examined in New Zealand from 1928 onward confirmed this view (Finlay, N.d.), and this difference remains.

Conclusion

New Zealand's stocks of anadromous chinook salmon are probably derived from the second of five consignments of ova in the early 1900's. These came from an undetermined tributary and hatchery on the Sacramento River, were taken to New Zealand in 1903, reaching there early in 1904; the first consignment (1900 brood year, reaching New Zealand in early 1901), which is known to have come from Battle Creek, a Sacramento tributary, may have failed to produce returns, though there could have been a a small and unnoticed return from this consignment. The explicit

source in the Sacramento River of the later shipments cannot now be determined.

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Survey Assessment of Semi–pelagic Gadoids: The Example of Walleye Pollock, *Theragra chalcogramma*, in the Eastern Bering Sea

WILLIAM A. KARP and GARY E. WALTERS

Introduction

Direct assessment provides essential information for the management of many marine fish stocks. Frequently, demersal stocks are assessed by means of bottom trawl surveys, and pelagic stocks are assessed using acoustic techniques together with some form of direct sampling such as midwater trawling. Each approach has its own strengths and limitations but these types of routine surveys provide critical information for many stocks.

When a stock is semi-pelagic (or semi-demersal) in habit, however, it is difficult to accomplish overall assessment with a single technique, and it may be necessary to assess the pelagic and demersal components independently. Because the biases associated with each technique differ, difficulties may be encountered when attempting to combine the data to produce a comprehensive estimate.

To address this problem, survey objectives should be evaluated. If the assessment process requires a survey-based estimate of overall abundance, problems associated with combining the two sets of data require careful consideration. But if it is satisfactory to provide indices of the abundance of certain portions of the stock, such as specific age groups, it may be possible to consider the pelagic and demersal assessments as independent sources of information, and problems associated with combining data sets would then be of less concern.

The walleye pollock, *Theragra chalcogramma*, resource of the continental shelf and slope of the Eastern Bering Sea (EBS) supports major fisheries activities. The species is semipelagic and is generally found in pelagic and demersal regions over bottom depths of 25–400 m, although it does occur in the pelagic zones of deeper waters (Sample and Bakkala, 1989). Greatest abundances are found along the outer continental shelf over water depths of 100–300 m (Wespestad and Megrey, 1990). Scientists from the NMFS Alaska Fisheries Science Center (AFSC) conduct the assessment of this stock. The demersal component of the stock is assessed annually during a multi-species bottom trawl survey of the EBS shelf. Small-scale surveys began in the early 1970's, and the present survey coverage was first established in 1975 and has been done annually since 1979. Also beginning in 1979, an expanded triennial bottom trawl survey has been conducted; this has covered a greater area of the shelf and the waters of the upper continental slope. During the triennial surveys, the pelagic component of the pol-

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ABSTRACT—Assessment of walleye pollock, Theragra chalcogramma, *in the eastern Bering Sea is complicated because the species is semi–pelagic in habit. Annual bottom trawl surveys provide estimates of demersal abundance on the eastern Bering Sea shelf. Every third year (starting in 1979), an extended area of the shelf and slope is surveyed and an echo integration–midwater trawl survey provides estimates of pollock abundance in midwater. Overall age–specific population and biomass estimates are obtained by summing the demersal and midwater results, assuming that the bottom trawl samples only pollock inhabiting the lower 3 m of the water column. Total population estimates have ranged from 134×10^9 fish in 1979 to 27×10^9 fish in 1988. The very high abundance observed in 1979 reflects the appearance of the unusually large 1978 year class. Changes in age–specific abundance estimates have documented the passage of strong (1978, 1982, and 1984) and weak year classes through the fishery. In general, older fish are more demersally oriented and younger fish are more abundant in midwater, but this trend was not always evident in the patterns of abundance of 1– and 2–year–old fish. As the average age of the population has increased, so has the relative proportion of pollock estimated by the demersal surveys. Consequently, it is unlikely that either technique can be used independently to monitor changes in abundance and age composition. Midwater assessment depends on pelagic trawl samples for size and age composition estimates, so both surveys are subject to biases resulting from gear performance and interactions between fish and gear. In this review, we discuss survey methodology and evaluate assumptions regarding catchability and availability as they relate to demersal, midwater, and overall assessment.*

lock stock has also been assessed by means of an echo integration—midwater trawl (EIMWT) survey.

In this paper we evaluate the methodology and results of the pollock assessments conducted during the triennial surveys as an example of semi-pelagic gadoid assessment. In considering the sources of bias, we offer suggestions for research and changes in methodology which may lead to improvements.

Methods

Detailed information on survey methodology was presented by Bakkala and Wakabayashi (1985), Bakkala et al. (1985), Walters et al. (1988), and Bakkala et al. (1992). Here we provide an overview of bottom trawl and EIMWT techniques.

Bottom Trawling

Assessment of demersal pollock on the EBS shelf and slope is conducted within the broader objectives of a multispecies bottom trawl survey designed to assess the condition of stocks of several species. Surveys are performed annually during the months of June, July, and August when migratory activities are believed to be minimal. Every third year a more comprehensive survey, covering a larger area of the shelf and slope, is carried out. Details of the triennial survey design are presented by Bakkala (1988) and an illustration of the area sampled is presented in Figure 1.

An Eastern otter trawl (type 83–112) with 900 kg steel V-doors has been used for sampling since 1982 (Table 1). Previously, a similar but smaller net, the 400 mesh Eastern trawl with 570 kg doors, was used. Both trawls were constructed of the same mesh sizes (Table 1), however, the 83–112 was rigged with 30 cm chain extensions on the footrope ends to improve bottom tending characteristics.

Prior to 1988, trawl width (wingspread) measurements were made on only a few tows made by any vessel with a given trawl. The averages of the measured widths were then used for all tows within an annual survey by that vessel and trawl. Beginning in 1988, the acquisition of sufficient mensuration equipment allowed measurements for almost every tow. Examination of these data revealed that trawl operating width is primarily a function of the amount of trawl warp extended (Rose and Walters, 1990). This analysis indicated mean widths-per-tow of 12–20 m over bottom depths of 20–200 m. Warp extended over these depths ranged from 90 to 550 m.

Time on the bottom and the distance fished for each haul were determined from the time and location where the winch brakes were set to the time and location of the beginning of haul back. Based on depth readings from the trawl mensuration equipment, trawl settling time was considered insignificant at depths encountered on the EBS shelf. The locations of the vessel at the start and end of each haul were obtained from LORAN C instruments. Biological information was obtained from the catches so that biomass and population abundance could be estimated by species, size, and age; catches greater than 1 metric ton (t) were subsampled using procedures designed to ensure randomness (Hughes, 1976; Bakkala et al., 1985).

Analytical procedures were described by Wakabayashi et al. (1985). An area swept technique which incorporates the wingspread and distance fished measurements described above, was used to develop biomass, population, and size composition estimates (Alverson and Pereyra, 1969; Doubleday and Rivard, 1981). Each catch was standardized into catch per unit of area. The standardized catches within a stratum were then used to estimate stratum biomass, and the stratum estimates were summed over the entire area. Length-frequency data and age-length keys, developed from fish sampled during the survey and aged from otoliths, were applied to the data to provide stratum and overall survey estimates of size composition and age composition.

Until 1990, the standardized catches of each species by each vessel were compared using a Bayesian approach (Geisser and Eddy, 1979). If significant differences between vessels were found for a particular species, the catches of the least efficient vessel were adjusted to be equivalent to catches from the most efficient vessel for that species by the ratio of the mean catches per unit effort (CPUE). Because this method was based on the estimation of a ratio, it was sensitive to occasional large CPUE values. Beginning in 1990, a new method developed by Kappenman[1] was used to compare the distribution of CPUE values based on a power transformation and develop a scaling factor for adjustment. This method has been applied to the time series of data back through 1982.

[1] Kappenman, R. F. 1992. Estimation of the fishing power correction factor. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Alaska Fish. Sci. Cent. Proc. Rep. 92–01, 10 p.

Table 1. — Trawls used during the triennial eastern Bering Sea groundfish surveys.

	Bottom trawls		Midwater trawls			
Characteristics	400-mesh Eastern trawl	83–112 trawl	Norsenet trawl	Northern Gold 1200 trawl	Diamond 1000 trawl	Gourock rope wing trawl
Years trawl used	1979	1982–91	1979	1988–91	1982–85	1982
Horizontal opening while fishing (m)	12.2	12–20	35	40–50/Unk.[1]	16.5–18.3	27.4–32.9
Vertical opening while fishing (m)	1.7	2–2.3	27–30	30–40/18–25[1]	16–19	27–33
Headrope Length (m)	21.6	25.3	Unknown	90.8/94.5[1]	54.0	102.1
Footrope Length (m)	28.7	34.1	Unknown	84.9/50[1]	54.0	102.1
Mesh sizes (mm)						
Wing	102	102	1000	Rope	406	Rope
Body	102	102	1000	1630–76	813–89	1626–813
Intermediate	89	89	800–80	96–89	89	406–121
Codend	89	89	46	89	89	89
Codend liner	32	32	38	32	38	32
Door (m)						
Length	2.1	2.7	3.0	2.7	2.1–2.7	6.0
Height	1.5	1.8	2.0	1.8	1.5–1.8	6.0
Dandyline						
Length (m)	45.5	54.9	165	82.3	54.9	91.4

[1] 1988 configuration/1991 configuration.

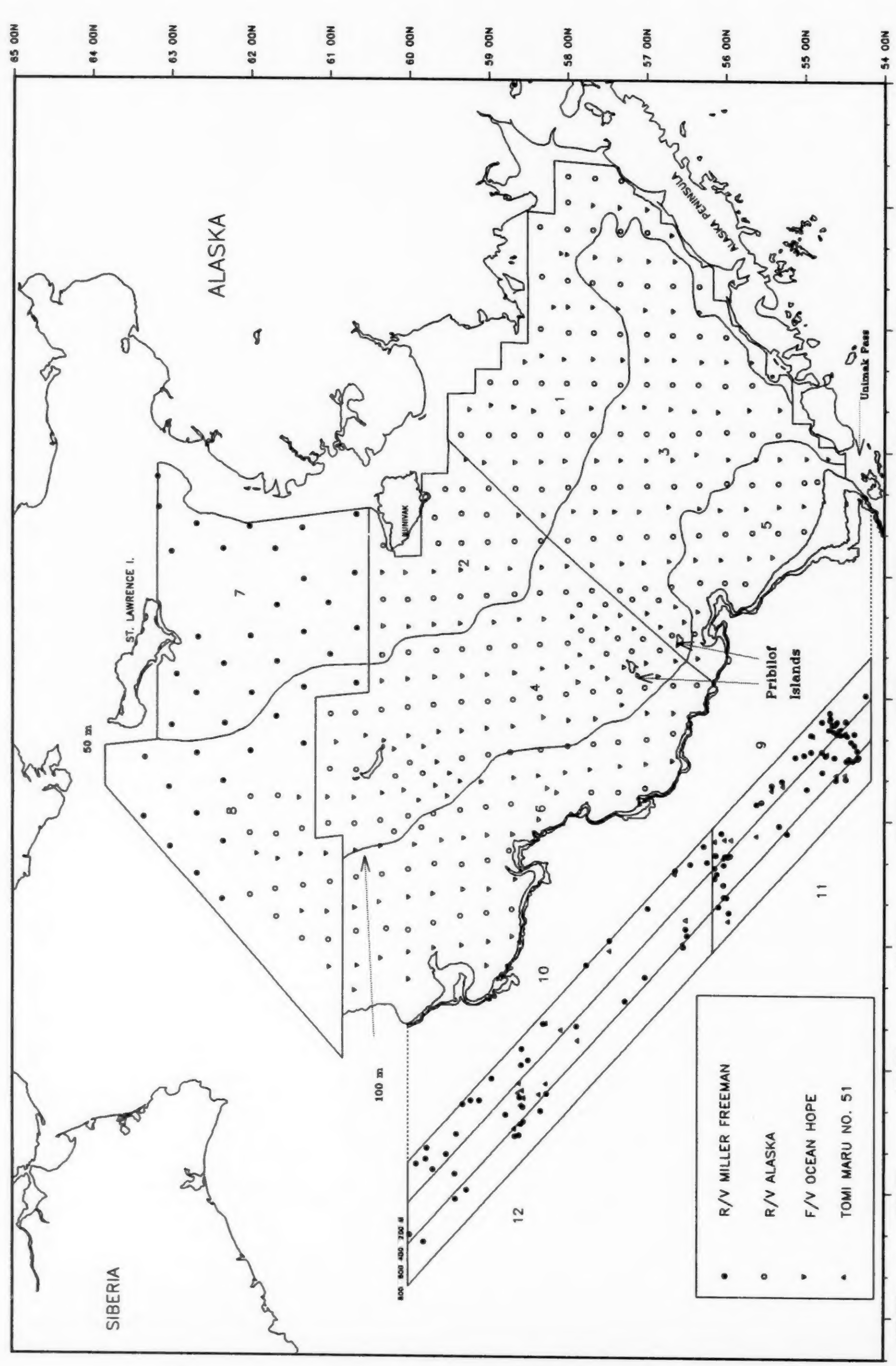

Figure 1. — Trawl stratification and survey design used in 1988 over the eastern Bering Sea shelf and slope.

Acoustic and Midwater Trawl Assessment

The acoustic method for pelagic stock assessment is based on the principle of echo integration. An echo sounding system transmits discrete pulses of sound into the water and waits for a period of time to receive echoes from targets in the insonified volume of water. The received echoes, in the form of voltages, are then fed into an echo integrator which squares and sums the voltage samples. The output of the echo integrator is proportional to the density of the fish insonified (Dragesund and Olsen, 1965; Forbes and Nakken, 1972; Burczynski, 1982).

Conversion of relative to absolute biomass estimates is dependent upon consistent system performance as monitored by calibration procedures and information regarding the acoustic properties of the fish in the form of mean acoustic target strength (TS). TS is dependent on species, size, behavior, and, in some cases, depth. Since small changes in mean TS can give rise to large errors in biomass estimation, direct in situ measurement of TS is generally recommended (Ehrenberg, 1983; Foote, 1991).

Techniques for the U.S. EIMWT surveys were described by Karp and Traynor (1989) and Traynor and Nelson (1985). Additional details were reported by Bakkala et al. (1985) and Walters et al. (1988). Transect lines were surveyed by means of a scientific quality 38 Khz acoustic system consisting of a transmitter, a towed transducer, a receiver, and a computer based digital echo integrator. The acoustic system was installed in a portable van that could be located on the deck of the survey vessel. When conditions were suitable, in situ target strength studies were conducted in order to collect target strength distribution information for a range of fish sizes and behavioral patterns. Dual-beam and split-beam techniques (Traynor and Ehrenberg, 1979) have been employed for this purpose, although most data has been collected with a split-beam system in recent years.

Since we do not yet have sufficient information to enable us to apply field measurements of TS during analysis of survey data, alternative approaches have been used as an interim measure. Before 1988, a TS value of –30 dB/kg was applied in the conversion of integrator values to estimates of biomass; starting in 1988, however, the empirical target strength/length relationship developed by Foote and Traynor (1988) (TS = 20 log (Fork Length (cm)) – 66.0) has been employed and has provided results which are generally consistent with in situ measurements.

The acoustic system was calibrated before and after each survey. The underwater acoustic calibration system available at the University of Washington's Applied Physics Laboratory was employed to conduct standard transmit and receive response and equivalent beam angle measurements. Also, beginning in 1988, the standard target technique, as described by Foote et al. (1987) was adopted and is now carried out in situ to monitor system performance at intervals during each survey.

Midwater trawling was an integral part of each survey. A large midwater trawl was used to collect biological samples when significant echo sign was encountered during the acoustic transects. Midwater trawl types and specifications have changed several times during the period that these surveys have been conducted (Table 1). As indicated in the table, different trawls were used for sampling juvenile and adult pollock sign. The vertical opening of each net was monitored with a netsonde. Towing speed in all surveys was approximately 1.5 m/sec.

Fishing was carried out on an opportunistic basis in order to collect adequate samples from the different types of echo sign encountered throughout the survey area. Since contamination with other species occurred infrequently, the primary objective of this sampling was to provide sufficient data for partitioning the acoustic estimates of biomass by size and age, and developing size and age specific population estimates. The information collected from these trawls was not used to provide quantitative information on abundance. Catches were processed in a manner similar to that described for the demersal trawl surveys. Age composition was determined by means of age-length keys obtained by analyzing otoliths taken from fish sampled randomly from most catches.

All EIMWT triennial surveys have taken place in the summer, during the same general time period as the bottom trawl surveys. In 1979 only the outer portion of the shelf and the upper slope were surveyed (Traynor and Nelson, 1985). In 1982 the entire shelf and upper slope over bottom depths from about 40 to 500 m was surveyed with a zigzag transect design (Bakkala et al., 1985). Subsequent surveys have covered most of the shelf waters deeper than 50 m and the slope. Starting in 1985, equidistantly-spaced parallel transect survey designs (e.g., Fig. 2) have been employed (Walters et al., 1988; Bakkala et al., 1992).

Results

Because the general objective of this contribution is to discuss the methodology for overall pollock assessment in the EBS, this section will concentrate on the types of information produced during the triennial surveys. Results of the 1979, 1982, 1985, and 1988 triennial shelf/slope surveys were reported by Bakkala and Wakabayashi (1985), Bakkala et al. (1985), Walters et al. (1988), and Bakkala et al. (1992), and the results of more detailed analysis of data from these surveys were presented by Karp and Traynor (1989), Sample and Bakkala (1989), and Traynor et al. (1990a). Results of the 1991 survey were not available when this report was prepared. Rather than present detailed figures of pollock distribution for each survey, the 1988 results are provided as an example (Fig. 3–5). Similar figures for the preceding triennial surveys were provided by Karp and Traynor (1989).

The 1988 survey results indicated patterns of distribution similar to those observed during previous triennial surveys. Taken independently, neither the bottom trawl nor the EIMWT survey results provide complete information on the horizontal distribution of pollock (Fig. 3, 4). Most demersal pollock occurred in waters deeper than 100 m, and

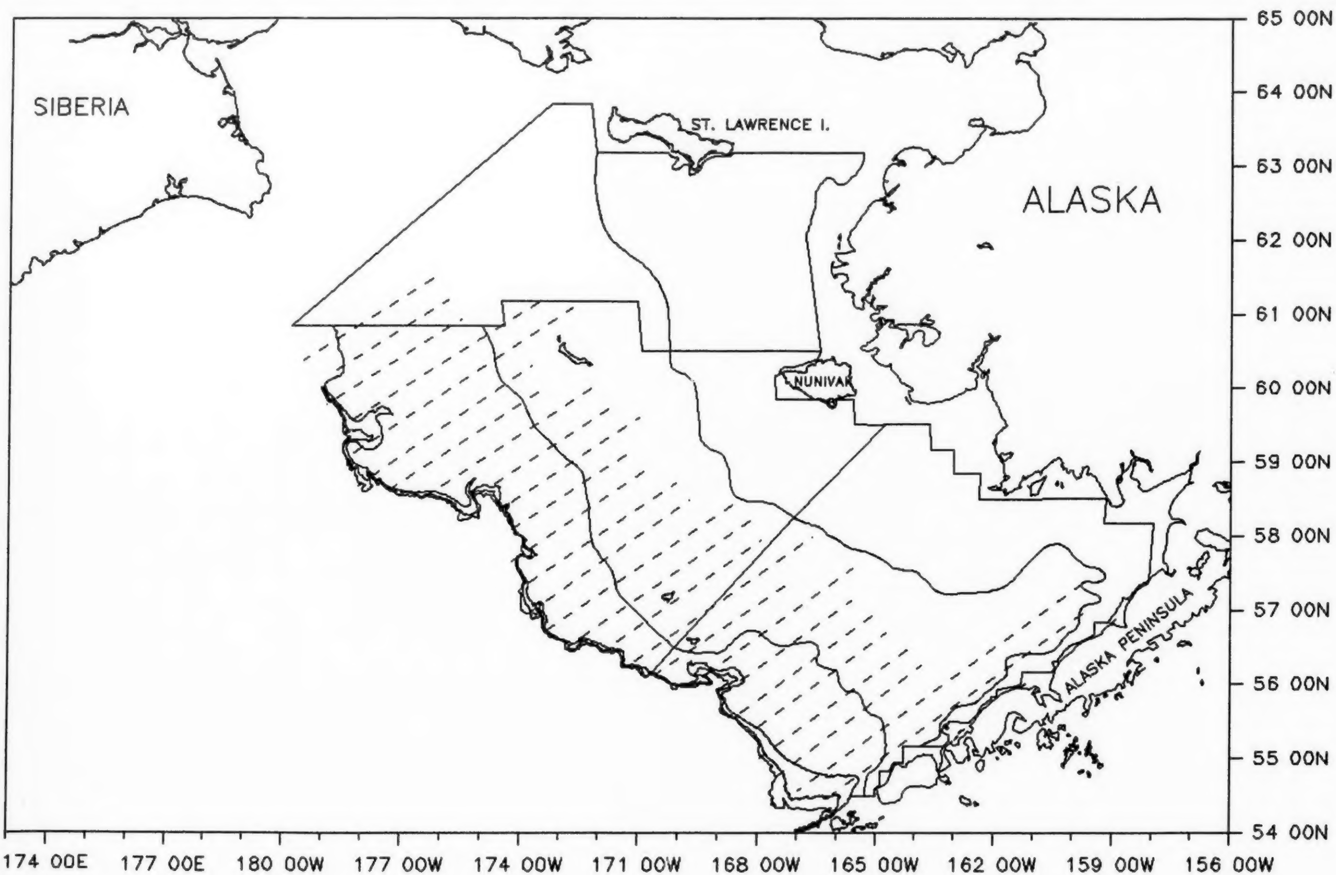

Figure 2. — The echo integration and midwater trawl survey design used in 1988 on the eastern Bering Sea shelf and slope.

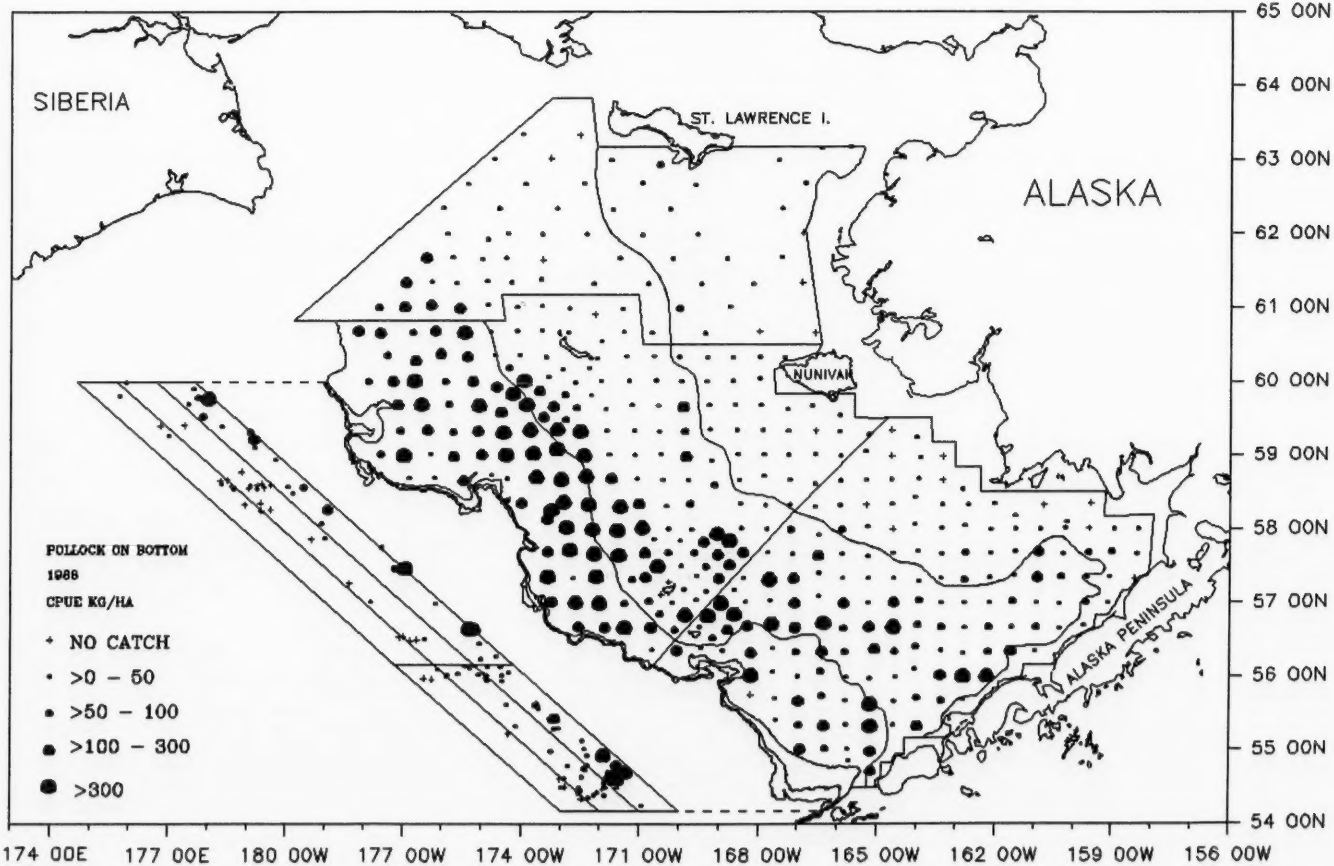

Figure 3. — Distribution and abundance of age 1 and older walleye pollock near bottom as determined during the 1988 triennial eastern Bering Sea shelf and slope bottom trawl survey.

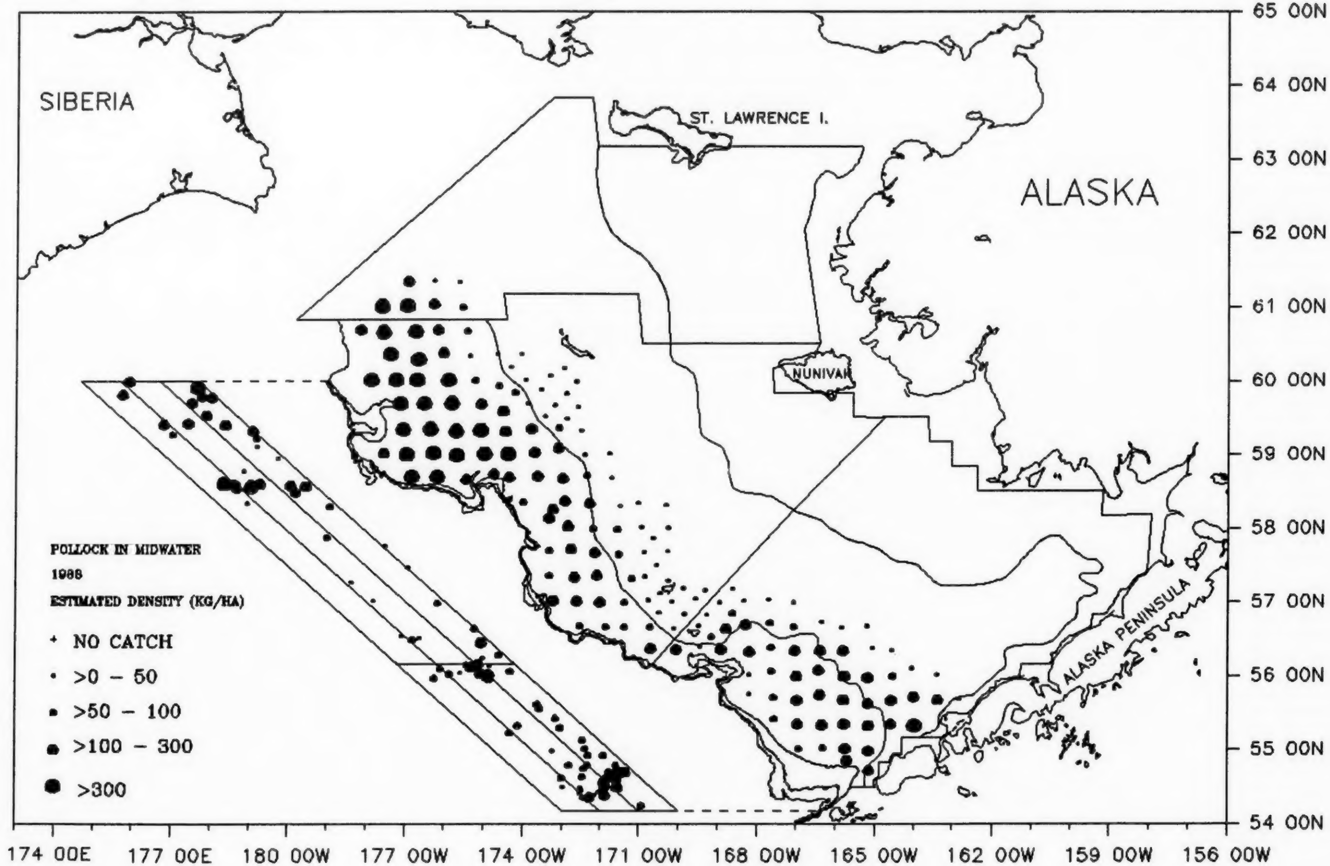

Figure 4. — Distribution and abundance of age 1 and older walleye pollock in midwater as determined during the 1988 triennial eastern Bering Sea shelf and slope EIMWT survey.

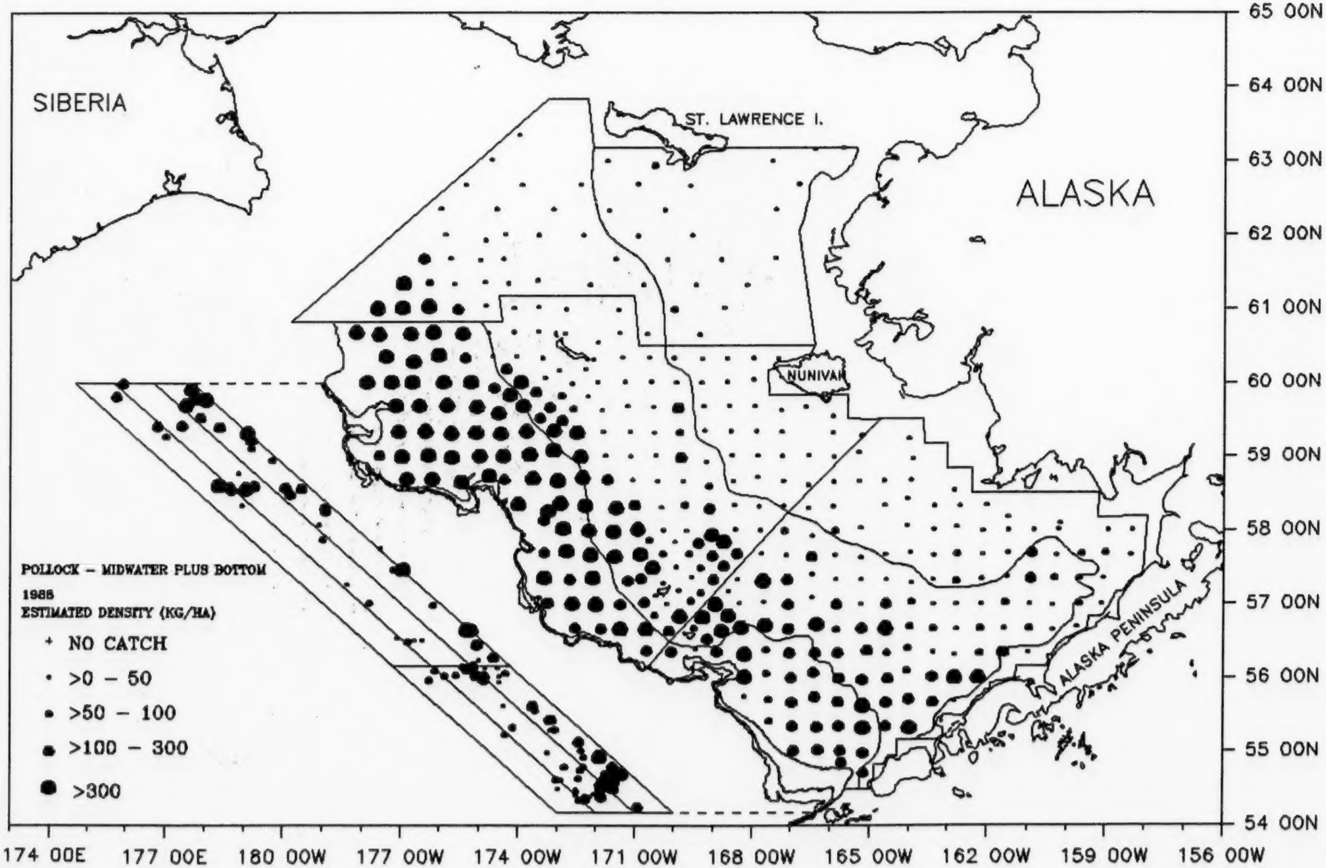

Figure 5. — Distribution and abundance of age 1 and older walleye pollock near bottom and in midwater as determined by combining bottom trawl and EIMWT estimates for the 1988 triennial eastern Bering Sea shelf and slope survey.

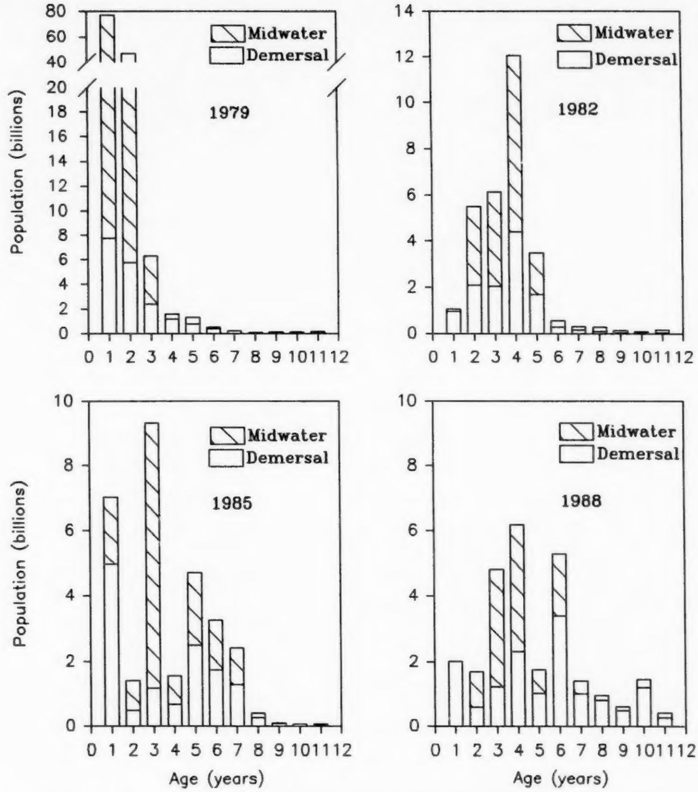

Figure 7. — Age-specific walleye pollock population estimates for midwater and demersal assessments conducted in 1979, 1982, 1985, and 1988.

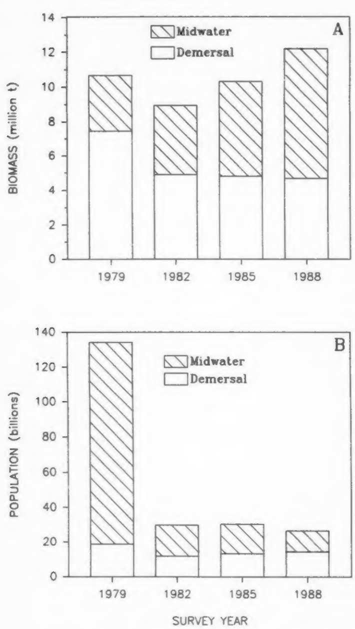

Figure 6. — Eastern Bering Sea shelf and slope walleye pollock biomass (A) and population (B) estimates for 1979, 1982, 1985, and 1988, illustrating proportions of estimates in midwater and near bottom.

few were found in trawls conducted in water shallower than 50 m. Pelagic pollock were more abundant in waters deeper than 100 m. Localized areas of high abundance generally occurred in the vicinity of Unimak Pass and south of the Pribilof Islands, and overall pollock abundance was usually higher to the north and west of the Pribilof Islands than elsewhere (see Figure 1 for location of depth contours and geographic sites). EIMWT surveys alone would not have documented the presence of pollock in shallower waters of the continental shelf, but, by combining the two types of survey data, it was possible to produce a more comprehensive map of distribution which indicated the trend of increasing overall abundance with depth (Fig. 5).

Comparison of results from the four combined demersal trawl and EIMWT surveys conducted over a 10-year period indicates substantial differences in abundance and vertical distribution between years (Fig. 6). Differences in the age-specific proportions of pollock found in midwater and on bottom are also apparent (Fig. 7, 8). For example, the proportion of 1- and 2-year-old fish in midwater was much greater than on bottom in 1979, whereas the proportion of age 1 fish on bottom exceeded that in midwater in subsequent survey years; age 2 and 3 fish were more abundant in midwater than on bottom during each survey, but age 4 fish were more abundant demersally in 1979 and in midwater in 1982, 1985, and 1988. The proportion of fish older than 5 years assessed by bottom trawl always exceeded the EIMWT derived proportion; this supports the perception that demersal orientation is more common for older fish (Fig. 9). The extremely strong 1978 year class undoubtedly influenced the unusual vertical distribution of juvenile fish that was observed in 1979. Our ability to track the progress of this year class over a 10-year period has been greatly enhanced by the use of both assessment methods. It is apparent that the variability of age-specific distribution in the midwater and demersal zones, overlaid on the general trend of increased demersal orientation with age, could not have been adequately documented by one assessment method alone. In addition, this combined assessment approach has enabled us to better document the progression of the above average year classes of 1982 and 1984. Many of the trends and patterns observed in the time series of data can be reasonably attributed to differences in year class strength, overall abundance, and recruitment to the shelf and slope stocks. Nevertheless, it is likely that some of our perceptions

have been influenced by biases that are inherent in our survey techniques. For example, the total abundance of the 1981 year class appeared to increase between 1982 and 1985. This suggests that this year class was not fully available to either (or both) surveys at age 1.

Limitations

Biases of concern to scientists conducting these surveys can be classified into three principal categories: those associated with deficiencies in biological knowledge; those associated with fishing gear, fish behavior, and the catching process; and those associated with the technique of echo integration.

Biological Considerations

The category of biological knowledge includes migratory activities and factors relating to stock identification. Detailed knowledge of patterns of stock distribution in space and time is an essential prerequisite for assessment survey design. Since these surveys have been conducted over relatively short time periods, when EBS pollock are believed to be in a nonmigratory feeding mode, horizontal migrations are not considered to be a serious source of bias. However, assumptions regarding the geographical distribution of the stock are based on limited information and it is generally recognized that the stock extends into unsurveyed areas of the western Bering Sea. Stock identification is of particular concern with regard to the origin of fish caught in the central Bering Sea and adjacent to Bogoslof Island (lat. 54°N, long. 168°W). The midwater and demersal surveys have not always been synchronous. This is a potential source of bias if significant migration does occur.

Vertical migration is also of some concern. The demersal trawl surveys are conducted only during daylight hours to avoid possible inconsistencies. EIMWT surveys have been carried out on a 24 hour per day basis. Even though diel changes in vertical distribution are apparent, it has been assumed that movement between the pelagic and demersal zone is not significant and that possible biases are minimal due to the short darkness period during the summer. Interannual changes in vertical distribution have been observed and the resultant changes in availability to each survey technique are a cause of serious concern.

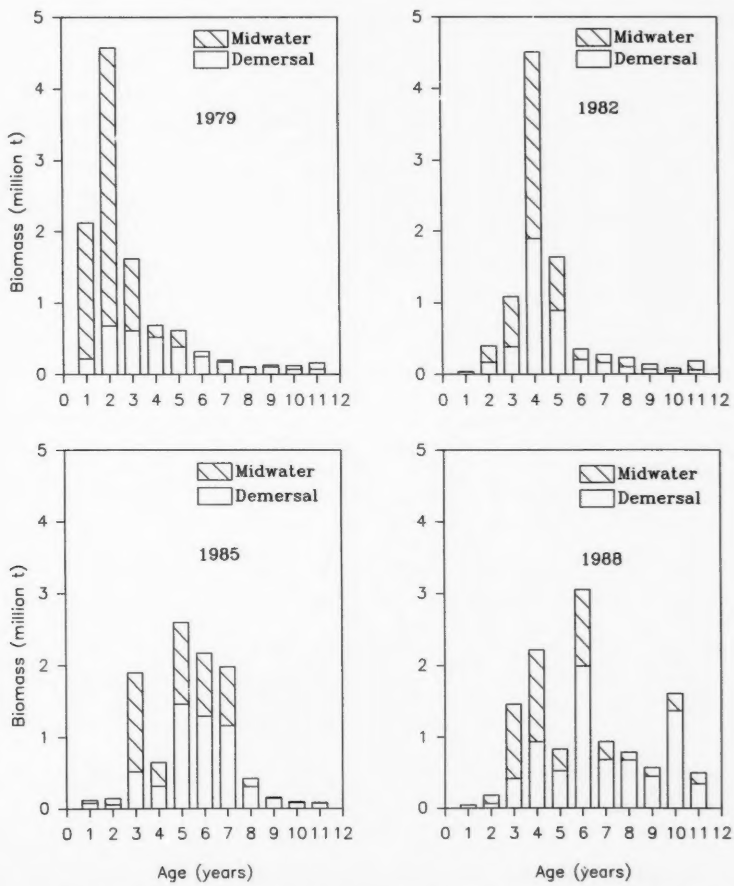

Figure 8. — Age-specific walleye pollock biomass estimates for midwater and demersal assessments conducted in 1979, 1982, 1985, and 1988.

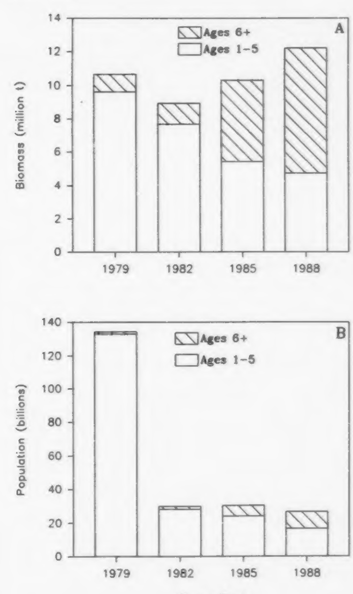

Figure 9. — Eastern Bering Sea shelf and slope walleye pollock biomass (A) and population (B) estimates for 1979, 1982, 1985, 1988, illustrating proportions of estimates of age 1–5 and age 6 and older fish.

Fishing Gear and Fish Behavior

Concerns regarding vessel avoidance, gear performance, and interactions between gear and fish during bottom trawl surveys have received a great deal of attention (Clark, 1979; Engås and Godø, 1986; Koeller, 1991; Olsen, 1990; Ona and Godø, 1990; Wardle, 1986). The development of instruments for monitoring some aspects of gear performance has been of great importance in this context. Such equipment is now used on a routine basis during EBS bottom trawl surveys (Rose and Walters, 1990).

The estimates of wingspread used prior to 1988 introduced bias into the pollock abundance assessment process because they did not account for the effect of varying scope. These early estimates were based on averages of small numbers of measurements taken in various locations, and for each survey the mean wingspread for the net aboard each vessel was used to estimate area swept. Work by Godø and Engås (1989) and Rose and Walters (1990), among others, has demonstrated that trawl width increases with scope. Most pollock are found in deeper water, where scope lengths and, therefore, wingspreads are greater than average. Thus for the greater proportion of pollock catches, net wingspread would have been underestimated and biomass overestimated. Since juvenile pollock are generally found in shallower waters than adults, it is likely that this source of bias incorporates an age-specific component.

In the area-swept calculations, it is assumed that the effective width of the net is equivalent to the wingspread. Work by Engås and Godø (1989a) indicates that the effective width of a demersal trawl used for sampling gadoids is related to fish size. In general, they demonstrated that, as sweep length (distance between trawl doors and net) was increased, catch rates of Atlantic cod, *Gadus morhua*, and haddock, *Melanogrammus aeglefinus*, increased with increasing fish length. They concluded that the herding effect is greater for larger fish. Loss of small fish under the net, as observed by Engås and Godø (1989b) is thought to be minimal in the EBS surveys because the net does not have roller gear and is rigged to dig into the bottom slightly in order to better sample crabs.

The second component of the area-swept estimate is distance travelled along the bottom. Net contact with bottom does not occur until after the winch brakes are set and the gear settles. The rate at which the gear settles is influenced by winch and vessel speed, water currents, depth, and net construction. At the end of the tow the net does not lift off as soon as the winches are turned on. However, the actual forward motion of the net across the bottom during haul back is difficult to determine. Even if the exact distance were known, the degree to which it is appropriate to correct for time off bottom is not clear because of the confounding effect of species and size related patterns of behavior. Beginning in 1993, new techniques will be used to address this problem. By using a time-depth recorder fitted to the net and Global Positioning System (GPS) navigation, exact time and position of settling and lift off can be determined. Thus haul duration can be measured and anomalous gear behavior identified. However, techniques are not yet available for observing how well the gear stays in contact with the bottom (bottom tending). There is also some concern that the area swept is based on distance travelled rather than the quantity of water passing through the net. Gear flowmeters are available to investigate this issue but they have not yet been used during AFSC surveys.

The procedure for fishing power correction (FPC), or standardization of observations to the most efficient vessel-gear combination has also changed in recent years. The new technique is considered to be more statistically appropriate than the method employed previously. However, the FPC procedure considers only species-specific effects and does not take size-specific factors into consideration. Also, the decision to adjust area swept estimates to the most efficient vessel-gear combination is based on the implicit assumption that catchability cannot exceed unity.

Younger pollock tend to remain in the water column and older fish are generally more demersally oriented. Several researchers (e.g., Olsen, 1990; Nunnallee[2]) have demonstrated that gadoids may dive in response to perceived disturbance from vessels and/or trawls. This behavior could lead to changes in relative availability to each assessment method. Size specific differences in patterns of avoidance are also likely. With the exception of 1979, the demersal survey biomass estimate of age 1 fish has always been higher than that obtained by EIMWT. Midwater estimates of age 2 and 3 pollock are generally higher than in the demersal survey, but the reverse is true for most ages greater than 3 in the majority of years. If the demersal trawl gear that was introduced in 1982 sampled age 1 fish with greater efficiency than before, this could partially explain the unusually high proportion of age 1 fish observed by the EIMWT method in 1979. It should be noted, however, that the 1978 year class was extremely large, and its midwater abundance in 1979 was very high. The change in gear type has undoubtedly compromised the integrity of the time series of data in a number of ways. Unfortunately, however, limited resources and inclement weather have precluded any meaningful comparison of the two trawl types.

Size and age composition of the midwater component of the stock is estimated by applying the information obtained from midwater trawling to the echo integration results. Thus, the degree to which the trawl samples represent the actual composition of the echo sign is a fundamental concern. The process of judging echograms and assigning biological characteristics based on trawls is somewhat subjective. Hylen et al.[3] believe the process of assigning bio-

[2] Nunnallee, E. P. 1991. An investigation of the avoidance reactions of Pacific whiting (*Merluccius productus*) demersal and midwater trawl gear. Pap. pres. to Fish Capture Committee, Int. Counc. Explor. Sea, C.M. 1991, paper/B:5, Session U.

[3] Hylen, A., O. Nakken, and K. Sunnana. 1986. The use of acoustic and bottom trawl surveys in the assessment of north-east Arctic cod and haddock. *In* M. Alton (Compiler), A workshop on comparative biology, assessment, and management of gadoids from the North Pacific and Atlantic oceans, part II, p. 473–498. Rep. on file at Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

logical characteristics to be a principal source of error in the determination of size and species specific acoustic abundance estimates (Aglen, 1989). Errors that result from avoidance, selectivity, or herding will be reflected in the size- and age-specific abundance estimates. Of particular concern are size-specific phenomena such as selectivity, or differences in avoidance reactions. The observations of Engås and Godø (1989b) regarding the greater degree to which larger gadoids are herded into the path of a bottom trawl are probably also applicable in the pelagic zone; one might also expect greater escapement of small fish through the rope wings of the midwater trawl. It is not known if the diving avoidance behavior observed by Nunnallee[2] occurs to a greater degree in larger fish, but their stronger swimming abilities and greater stamina suggest this possibility.

Echo Integration

Calibration is an essential component of a quantitative acoustic assessment program. The system was calibrated frequently, and echo sounder performance was monitored during the surveys.

Due to the limited dynamic range of the echo sounder and the need to set an integration voltage threshold high enough to eliminate extraneous noise, we undoubtedly obscured acoustic returns from low density distributions of pollock during these surveys. The degree to which this resulted in underestimation of abundance is unknown, but our general observations of the pattern of pollock aggregation and distribution suggest that this problem was not severe, especially since the survey area is relatively shallow.

Before 1988, a constant average TS value was used in biomass estimation calculations. Selection of too low a mean TS value would have led to an overestimate of fish abundance; this would have been more likely when smaller fish predominated, such as in 1979. This is because, in general, the TS per unit weight for small fish is greater than for large fish. The use of observed fish length compositions and the empirical TS-length relationship of Foote and Traynor (1988) to compute mean TS in 1988 makes some progress towards addressing the problem but relies heavily on the assumption that the midwater trawl catches accurately represent the size composition of the fish sampled acoustically (further implications of this assumption are discussed below). In the EBS, schools of juvenile fish are generally spatially separate from schools of adults, so that the effects of selectivity may be less severe in this context. Neither TS estimation technique has been able to take into account behavioral and other factors that influence fish target strength (Traynor et al., 1990b).

An accurate measure of the acoustic pulse width is essential if biomass estimates are to be obtained by echo integration. The acoustic pulse width provides one dimension of the computation used to determine the amount of energy transmitted into the water. If uncorrected, an erroneous assumption that the pulse width is too wide will lead an underestimate of abundance. The reverse is also true. A computer program was developed to sample the rectified voltage signal from individual fish targets and calculate the effective integration pulse width (Traynor and Nelson, 1985).

Sound energy decreases with distance from the transducer due to spreading and attenuation. To compensate for this, echo sounder receivers incorporate a time varied gain (TVG) amplifier and provide for an estimate of attenuation due to absorption by seawater. The AFSC acoustic system TVG function is measured using a computer program that samples calibration oscillator signals at 1 m intervals. Deviations from the theoretically correct TVG were determined and corrected as described by Traynor and Nelson (1985). If uncorrected, deviations from the theoretically correct TVG could lead to biased estimates of abundance. Overcorrection (too much gain) would cause overestimation and undercorrection would cause underestimation.

The acoustic system and operating procedures were designed to minimize the effects of self noise. Self noise is the sum of noise components contributed by the vessel and the electronic equipment. Since low-noise, scientific quality instruments were used, the principal potential source of self noise was the survey vessel. During these surveys, vessel noise was minimized by selection of appropriate engine speed and propeller pitch, and, on occasion, suspending survey operations during inclement weather.

Reverberatory noise occurs when the transmitted sound pulse intercepts bubbles or biological sound scatterers (i.e., organisms other than the target species). In general, during the EBS surveys, most ambient or reverberatory sources of noise were eliminated or reduced to an insignificant level by setting an appropriate signal threshold and eliminating data from nontarget species during data processing. It should be noted, however, that the process of setting an appropriate system threshold is one of compromise; setting a threshold high enough to eliminate most extraneous noise will result in the elimination of returns from fish, especially at low levels of density. The transducer was generally towed deep enough to avoid near-surface noise from air bubbles but no deeper than the shallowest expected occurrence of pollock (Traynor et al., 1990b).

Separation of fish echoes from bottom echoes is subject to physical and operational limitations. System parameters limit the absolute ability of an echo sounder to separate near-bottom targets from the bottom itself and fish in contact with the bottom cannot be assessed by echo integration. Provided that echo integration is carried out in small discrete depth intervals, it is usually possible to eliminate unwanted bottom echoes from the data and include acoustic returns from fish within a short distance (2–3 m) of the bottom. This procedure was followed during AFSC data collection and analysis.

The methodology discussed above refers to the AFSC acoustic system that was in use through the 1988 triennial survey. Beginning in 1991, a new set of instruments, with improved stability, dynamic range, and signal-to-noise ratio has been employed (Knudsen, 1990). The basic methodology has not changed, but technical improvements have re-

duced the potential impact of some of the aforementioned concerns.

Overall Estimates

All the aforementioned biases are of concern when combining the results of the pelagic and demersal assessments. Each method is subject to a series of biases and it is likely that combining the two sets of estimates will exacerbate the effects. The basic assumption implicit in this procedure is that the effective sampling height of the bottom trawl is 3 m, that all demersal fish are fully available only to the bottom trawl, and all pelagic fish are fully available only to the acoustic assessment. It is also assumed that all sizes of fish in each zone have a catchability of unity to the respective assessment method. In the preceding paragraphs we have presented evidence to suggest that these assumptions may not be completely valid. For example, diving avoidance behavior may increase the availability of pelagic fish to the demersal trawl and reduce their availability to the pelagic trawl. This may result in inaccuracies in both demersal and pelagic size and age composition estimates. Godø and Wespestad (1990) postulate that this is indeed the case, and that it led to substantial overestimation of older fish in 1988, as indicated by a divergence of fishery based and survey based estimates in that year. Their argument is plausible because it considers the tendency of the bottom trawl to sample larger fish with greater efficiency in the horizontal plane due to herding and in the vertical plane due to diving avoidance behavior. The diving behavior would probably also lead to an underestimate of the proportion of larger fish in the pelagic region.

Preliminary results of the 1991 triennial survey add further weight to this argument (Williamson)[4]. With the new acoustic assessment system, pelagic pollock biomass estimates covered the water column down to 1.0 m off bottom. The preliminary pelagic biomass estimate was 2.1 million t and the preliminary bottom trawl estimate (covering the lower 3 m) was 5.0 million t. Extrapolation of the echo integration results to the bottom increases the overall EIMWT estimate by a relatively small amount. This suggests that the effective width of the bottom trawl is considerably greater than the distance between wingtips and the effective height is greater than 3 m.

As mentioned earlier, bottom trawl surveys are conducted during daylight, while acoustic and midwater trawl sampling are carried out during daylight and darkness. Much work has been done on the effect of diel changes on fish behavior and assessment results throughout the world (e.g., Engås and Soldal, 1992; Wardle, 1986; Woodhead, 1964) but this phenomenon has not been investigated extensively with regard to Bering Sea pollock assessment. The impact of these phenomena on survey results can be substantial, and considerable research is called for. It also seems reasonable to evaluate the manner in which survey data is used to tune the fishery based analysis; perhaps the demersal and pelagic estimates could be considered as independent estimates of the condition of certain sets of age groups. Sample and Bakkala (1989) demonstrated a highly significant regression when comparing bottom trawl and cohort analysis estimates of age 4–9 pollock abundance for the period 1979–86. Since the population ageing process is gradual, one might expect the size dependent phenomena discussed above to have influenced the annual bottom trawl (and triennial EIMWT) results gradually over a period of years. If this had been the case, it might have been apparent in the work of Sample and Bakkala (1989); it would be interesting to extend their analysis with recently obtained data.

Toward Improved Assessments

As we recognize the various problems associated with bottom trawl and EIMWT surveys we must address them in a systematic manner. In the light of recent work carried out at AFSC and elsewhere, appropriate research is being planned.

Relationships between net width and trawl warp determined by Rose and Walters (1990) have been applied to the historic 83–112 trawl data for which direct width measurements were not made. This enabled us to make corrections in the area swept estimates and investigate the degree of bias associated with assumptions regarding the horizontal opening of the net. Biases leading to overestimates in the earlier analyses (especially for trawls made in deeper water) were apparent in all but one year. Overall, the magnitude of the bias was approximately 3%, a value less than we originally expected. For species with predominantly inshore, shallow-water distributions, underestimation biases were indicated.

The CPUE values have now been used to reevaluate the FPC estimates necessary to complete a new set of biomass estimates for the time series. After applying these two sets of corrections, it will be necessary to review the multi-year data set. It must be recognized that these corrections will not account for all sources of error. For example, if wingspread exceeds design limitations, changes in gear performance can be expected. It has been argued that the FPC approach is no more than an interim solution and will be eliminated when we better understand fish behavior in relation to fishing gear and can take significant phenomena into account in our assessment process (Munro[5]).

Research will be directed towards in situ monitoring of gear performance and establishing techniques for maintaining performance within design limitations. The work of Engås and Ona (1991) on the use of restrictors for door spread shows promise in this regard.

The innovative approach to determining settling and haulback time and distance fished described above will help reduce errors in area swept calculations and enable us to better identify poor

[4] Williamson, N.J. NMFS Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115. Personal commun. Further information on recent stock assessments is provided in the 1993 stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands, and it is available from the North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

[5] Munro, P. NMFS Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115. Personal commun.

hauls. We are also concerned with the problems of subsampling large catches and interested in the recent work which investigated the advantages and disadvantages of shorter tow durations (Godø et al., 1990).

Other problems in fishing gear technology are more difficult to research and will require a major effort. It is essential that research on gear design and fish behavior in relation to fishing gear be assigned high priority if we are to understand and address the biases in our survey estimates.

The data presented above suggest that larger pollock are more demersally oriented but we are not sure of the extent to which this perception is tainted by interactions between fish and sampling gear. We are now able to collect continuous TS measurements through the water column during the surveys. Provided that suitable target densities can be encountered, and the single target selection algorithm is equally effective through the range of depths sampled, we will be able to use TS measurement data to examine possible trends in size with proximity to the bottom. It should also be possible to design experiments to investigate how such trends are influenced by the passage of a trawl. Because of the influence of fish behavior on TS these types of observations will have to be evaluated with caution.

The work of Engås and Godø (1989a) suggests that we must investigate the effect of sweep length on the size (and species) composition in our catches. This leads to a consideration of priorities. Because the trawl survey is designed to assess a multispecies community, it will probably never be possible to optimize the design with respect to pollock. Since most of the species sampled by the bottom trawl are truly demersal, perhaps we need to develop an alternate technique for assessment of this semi-pelagic species. Regardless, it is essential that we investigate the size and species-specific sampling efficiencies of our sampling trawls.

We believe that it may be possible to develop the EIMWT technique to produce satisfactory total water column estimates of pollock abundance. Recent work on problems of near-bottom detection (Ona, 1988 (cited in Godø and Wespestad, 1990) and Mitson, 1983) suggests that it may be possible to collect useful integration data very close to the bottom and make appropriate corrections for regions of the acoustic beam that are obscured in this near bottom region. While the physical limitations have not changed, our understanding of the limitations has improved, and newly developed tools for collecting and processing echo integration data will make it easier for us to conduct research in this area (Knudsen, 1990; Foote et al., 1991). It is important to bear in mind that this approach will still require us to make assumptions about fish distribution and behavior close to the bottom, and these assumptions may be difficult to test.

We will still be faced with some questions regarding trawl sampling biases when it comes to developing age specific abundance estimates. This will become even more critical if we are to expand our EIMWT method into the demersal zone. An alternative approach would involve using acoustic measurements to investigate and document availability of pollock to demersal gear. Much research remains to be done if we are to develop effective techniques for combining biological information from midwater and bottom trawls while accounting for the biases inherent in the use of each type of gear.

The methods described above are designed to provide estimates of absolute abundance. However, we have presented overwhelming evidence of substantial bias in our survey results. This supports the argument that survey results should be considered as indices of relative abundance that have significance only as elements in a time series. Even under this constraint, we must work under assumptions regarding the consistency of bias which may be difficult to support.

Realistically, however, we must consider the manner in which survey results are applied. Stock assessment models that are used to determine allowable biological catch (ABC) levels for commercial fisheries require a source of absolute abundance information. This can be obtained from analysis of historic fisheries data or from survey results. Analysis of fisheries data requires reliable time series of catch and effort information and realistic estimates of natural mortality and terminal fishing mortality rates.

For some fisheries, data are insufficient, and in other cases assumptions regarding mortality rate estimation may be difficult to support. This leaves us on the horns of a dilemma. Are we more willing to accept the assumptions implicit in developing absolute abundance estimates from survey data than those implicit in the analysis of fishery data? The problem can be resolved by taking a pragmatic approach, recognizing the limitations under which we are forced to work and making best use of the data that is available. Inevitably we will sometimes have no choice but to use survey results as measures of absolute abundance. This serves only to emphasize the need for all scientists involved in stock assessment to understand the limitations in their data and investigate approaches to improving the quality of information used in the stock assessment process.

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Fisheries Management: The Kuwaiti Experience

C. P. MATHEWS

Introduction

Siddeek et al. (1991) discussed very briefly some recent developments in Kuwait's shrimp fishery, including an important increase in landings of the main commercial species, *Penaeus semisulcatus*. This increase coincided with a marked fall in landings of the other important species, *Metapenaeus affinis*. They thought that these changes were caused by a reduction in effort combined with a more or less simultaneous favorable environmental change for *P. semisulcatus* and an unfavorable environmental change for *M. affinis*, but did not give any unequivocal evidence to support this conclusion. The results they reported are, nevertheless, very important and may be relevant to scientists and managers in other parts of the world.

Mathews and Samuel (1991) summarized some of the important results produced in Kuwait, but they were interested only in the implications for future research in tropical fisheries, especially for penaeid trawl fisheries. They did not address any of the items raised by Siddeek et al. (1991), nor did they discuss any of the research on shrimp recruitment carried out previously in Kuwait, i.e., migrations or the possible interactions with the oceanographic environment. This article therefore examines some of the more detailed scientific results that were used to justify the management measures taken and discuss some of the successes and failures of shrimp fisheries management in Kuwait.

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Impact of Wars on Kuwait's Fisheries

The Iraq-Iran war, which lasted from September 1979 until the autumn of 1988, frequently affected the distribution of fishing effort in Kuwait waters. The artisanal fisheries for pomfret, *Pampus argenteus*, taken in gill nets; snappers and groupers (mainly *Lutjanus coccineus, L. malabaricus, Epinephelus tauvina,* and *E. suilis*) taken with fish traps; and various species of trawled fish, were all excluded from fishing near the mouth of the Shatt-al-Arab for most of the war. The war also reduced or eliminated effort by artisanal trawlers on *M. affinis* nursery areas located near the mouth of the Shatt-Al-Arab, north of Failakka Island (area 3, Fig. 1). Industrial effort in this area (mostly by large Iraqi trawlers) was altogether eliminated. Reduction of artisanal and industrial trawler effort on shrimp grounds south of Failakka Island was not very severe or long lasting until September 1987 when security measures associated with the war excluded night fishing throughout Kuwait waters, with day fishing allowed in principle only 5–10 miles from the coast. In spite of these security problems, research and assessment work continued until the end of the Iraq-Iran war in 1988, and the government managed the penaeid fishery, often taking scientific advice into account.[1]

The disastrous invasion of Kuwait, which occurred on 2 August 1990 and lasted until the expulsion of Iraqi troops by U.N. forces in late February 1991, had much more severe effects. All research and assessments were suspended (Carpenter, 1992; Mathews et al., In press). Many fishing boats were moved to Iraq by conquering forces, and only a few have been returned so far. All equipment, databases, and scientific records were taken to the Marine Science Center, University of Barash, together with the Mariculture and Fisheries Department's library. None of these scientific resources have been returned. Although data collection was started some months after the end of the war, the significant stock assessment and management system installed before the war is not yet fully in place. Some data on landings and effort are available for

[1] Personal observations and communications from fishermen, government, and industry.

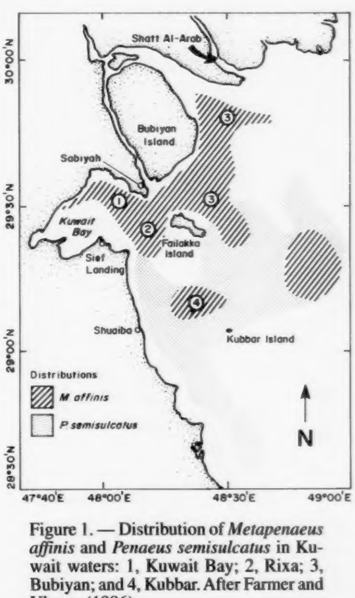

Figure 1. — Distribution of *Metapenaeus affinis* and *Penaeus semisulcatus* in Kuwait waters: 1, Kuwait Bay; 2, Rixa; 3, Bubiyan; and 4, Kubbar. After Farmer and Ukawa (1986).

1992–93 (Kuwait Institute for Scientific Research: Personal commun.) but full recovery from the impact of the war has not occurred. It is likely to be some years before the important prewar capability is fully restored. Therefore it is important to make full use of the Kuwaiti experience, using all published data.[2]

Development of Kuwaiti Assessment Research

Shrimp assessment research began in Kuwait in 1977 at the Kuwait Institute for Scientific Research (KISR), and by 1979 adequate time-series data were available for preliminary assessment of the stocks with surplus production and dynamic pool models. These results, together with falling shrimp catches in the Gulf between Iran and the Arabian Peninsula, were used to justify a longer closed season aimed at protecting spawners. The available data did not, however, provide an unequivocal justification for these measures.

In 1981, a detailed review of all available data and analyses was carried out by the KISR shrimp research team[3] (Mathews, 1982 a, b), and new assessments were provided. Yield per recruit (*Y'/R*) models justified:

1) An increase in the size at entry to the shrimp fishery (either through increasing mesh size or through establishing a longer and/or later closed season), and
2) A decrease in exploitation ratio (*E*).

The review also found that surplus production modeling justified a reduction in effort to a level of about 16–20 industrial boat-years (expending about 2,800–3,600 days per year). This measure would allow the fishery to operate at a much more profitable level. In spite of their more detailed assessments, the scientists involved chose not to recommend any management action, but did take care to inform managers of the scientific results and of their possible management implications (Mathews, 1982c).

In 1982, the KISR shrimp research team identified a new policy based on the separate management of the *P. semisulcatus* and *M. affinis* stocks, which have overlapping but largely separate fishing grounds (Fig. 1). These two species provide over 90% of the commercial landings by volume and value.

A study of *P. semisulcatus* spawning prior to the closure of the fishery showed higher than usual catch rates of sexually mature shrimp in 1982 which justified a later closure of the fishery: Fishing was allowed until early May 1982 instead of being suspended in late February (as was the case in 1981). This extension led to a significant enhancement of profits in the 1982 fishery.

At the same time the closed season was confined to the *P. semisulcatus* stock: Total closure of the fishery on *P. semisulcatus* was acccompanied by limited fishing on the *M. affinis* stock by industrial boats whose landings were monitored to ensure that no *P. semisulcatus* was taken. Fishing of *P. semisulcatus* was effectively forbidden by means of a strict ban on the landing and sales of the latter species (Mathews and Al-Ghafar, 1984).

Implementation on a trial basis of the two-stock management policy for 1983–85 led to total *M. affinis* landings during the closed season of about 1,000 t, worth about KD900,000 (i.e., about $US3,000,000), a sum markedly in excess of the total amount invested in shrimp assessment research during 1977–88. The success of the policy during its first year demonstrated the usefulness of fisheries management research to both government and industry and increased communication between them and the scientific research sector.

By 1983, the results being produced by the KISR research team were based on much more detailed analysis and preparation of data. Figure 2 shows the yield per recruit (*Y'/R*) model developed by Mathews and Al-Ghafar (1984, 1986); *A* shows the position of the fishery in 1982 (their reference year). The corresponding yield curve (*O'AO*) for that size at entry (18 mm carapace length) shows that very small changes in *Y'/R* will occur for any value of *F* from about $F = 1.5 - 6.0$; MSY for mean length at capture, Lc = 18 mm *CL*, occurs at about *A*. It is also clear that an increase in size at entry by any appropriate means would increase *Y'/R* from about *A* to *A"* at $F = 3.0$.

Figure 3 shows the surplus production curve these authors developed for the shrimp landed by the Kuwait Trawl Fishery. It may be compared with the yield curve (*O'AO*) developed from the *Y'/R* model, assuming that $F = gf$ (where f = annual effort in the trawl fishery in thousands of boat days per year, and g

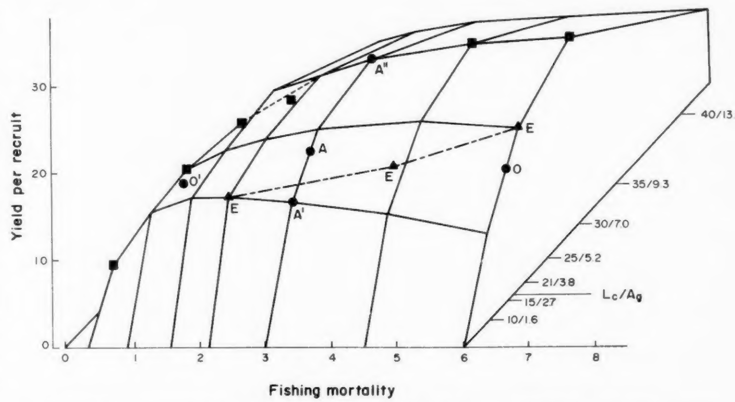

Figure 2. — Dynamic pool model of Kuwait's shrimp fishery. (Yield surface for *Penaeus semisulcatus*.) *Y'/R*: Yield per recruit; *Lc:* mean length at entry into the fishery in mm carapace length; *Ag:* mean age at entry to the fishery in months: 30/7.0 indicates 30 mm CL and 7.0 months old; *O* = *Y'/R* at present size at entry but higher effort; *O'* = *Y/R* at present size at entry but lower effort; *A* = *Y'/R* at present effort and size at entry; *A'* = *Y'/R* at present effort and lower size at entry. *A"* = *Y'/R* at present effort and higher size at entry. *E* = points on the eumetric curve; * = points at which *Y'/R* is highest for a particular effort level (*A'* is also one of these points).

[2] Personal communications, including information from eyewitnesses.

[3] See Acknowledgments.

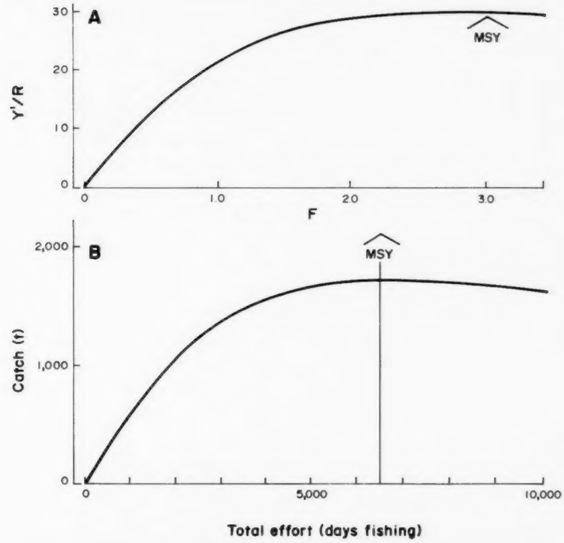

Figure 3. — A = Yield per recruit model of Kuwait's shrimp fishery at $Lc = 18$ mm CL (from Fig. 2). B = Surplus production model of Kuwait's shrimp fishery (Mathews and Samuel, 1991).

is the catchability); and placing $F = 3.0$ at an effort of 6,500 industrial boat-days per year. The two curves are very similar to each other, and any differences between them are more likely to be due to data problems and analytical problems, rather than to significant biological differences between the models.

Both models show a very long right hand limb with very small changes in catch corresponding to large changes in effort. The curve applies to a time period for which it is believed no change in size-at-entry occurred (but no data are available). Of course, changes in recruitment have occurred (e.g., Morgan and Garcia, 1982), but they seem to have been much smaller from about 1970 to the late 1980's than may have been the case in the late 1960's (Mathews and Al-Ghafar, 1986). This is why the Siddeek et al. (1991) observations (if correct) are so interesting.

Figure 4 (from Mathews and Al-Ghafar, 1984, 1986; Mathews and Samuel, 1991) shows a simple bioeconomic model developed from the surplus production model shown in Figure 3: Net profit is maximized at about 3,000 days per year, and MSY will be obtained at about 6,500 days per year.

The KISR shrimp research team communicated these results to management (e.g., Mathews, 1984) with the suggestion that a serious policy of effort reduction should be contemplated. Al-Hosseini et al. (1984) showed that it was impractical to manage the shrimp fishery by means of mesh size, further justifying the chosen policy of changing the opening date as the best means of increasing size at entry to the fishery.

The economic consequences of an effort limitation policy were explored in detail during 1985 (Mathews et al., 1986) and confirmed the above bioeconomic analysis. The following broad policy was recommended:

1) Reduction of effort from the high effort level of about 10,000–13,000 days fishing (1983–86) per year to about 3,000 days, for a policy of maximizing net profit (Fig. 4).

2) Establishment of buy-back policy so that effort limitation could be carried out. This was designed to make a policy of maximizing net profit feasible as well as technically possible.

3) Continuation of the two-stock management policy.

4) Delay in the opening of the shrimp fishing season from 1 July to 1 October so as to a) increase the value of the landings by increasing the average size of the shrimp landed, b) increase the size of the spawning biomass so that autumn spawners (spawning in September) were protected as well as spring spawners (FAO, 1982), and c) increase the catch rate of the spring spawners at the end of the fishing season, recommended to last until the end of January so as to

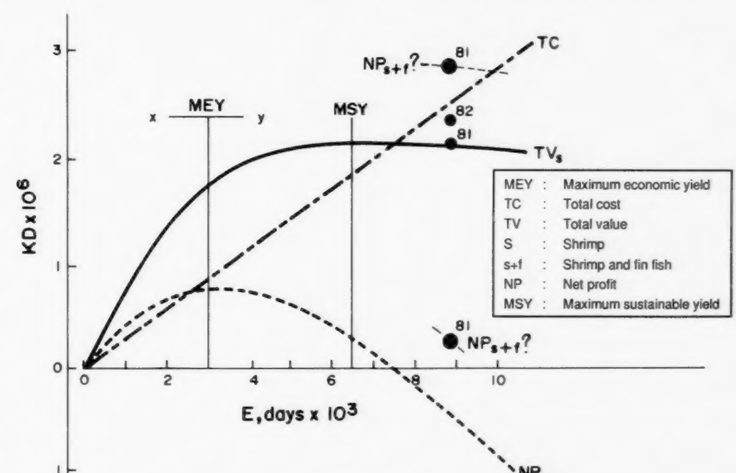

Figure 4. — Bioeconomic model of Kuwait's trawl fishery used to assess the profit structure of the fishery and to justify effort reduction (Mathews and Samuel, 1991). Numbers 81 and 82 indicate limited data including finfish as well as shrimp for 1981 and 1982, respectively.

reduce total effort and to protect the spring spawners (spring spawning occurring in about February to April; FAO, 1982).

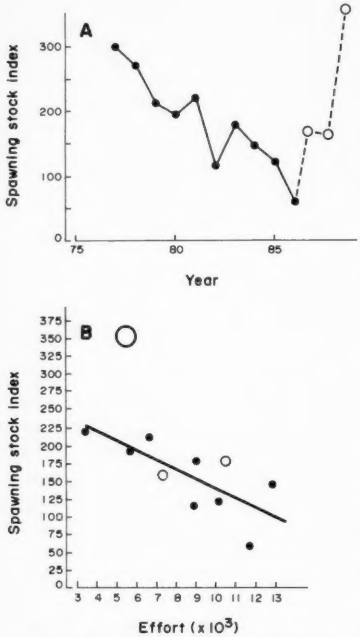

Figure 5. — A = Changes in the index of spawning abundance for *P. semisulcatus* over time (kg/standard day's fishing in January and February of each year). Dots are from Morgan (1989); circles = new data from Siddeek et al. (1991). B = changes in the index of spawning abundance (same units in the ordinate as Fig. 5 A). Dots are from Morgan (1989); circles = new data from Siddeek et al. (1991); large circle = datum for 1988–89 from Siddeek et al. (1991).

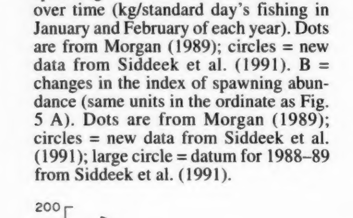

Figure 6. — Actually observed and predicted recruitment indices, the latter obtained using Morgan's (1989) stock recruitment model. The recruitment index used is the catch rate divided by *Y/R* at the relevant size at entry, and assumes that L_∞, *K*, *Lc*, and *M* are all constant (see text for limits on these assumptions).

5) Other possible and alternative strategies were identified for management choice, including a policy of harvesting at or near MSY at an effort level of about 6,000 days per year, increasing somewhat the profitability of the fishery, and reducing fishing costs substantially (Fig. 4).

In 1987, Morgan (1989) presented evidence relating recruitment and spawning biomass to effort expenditure (Fig. 5, 6) and showed that recruitment was probably reduced because of excessive effort expenditure (Fig. 6). He also related a probable decline in spawning biomass to the excessive expenditure of effort (Fig. 5).

Implementation

By late 1987 a series of significant research results had been presented to the industry and the Kuwait government at seven annual fisheries management workshops (e.g., Mathews, 1986a, b). The previous successful implementation of flexible closed seasons and closed areas, and the justified discarding of mesh size as a management tool, had led government and industry to accept that fisheries management was technically possible, and that it could reduce the risks and enhance the profits to fisheries entrepreneurs. This led government to rely on management-oriented research to assist in identifying possible management options. The combined research output described above therefore led to a reappraisal of Kuwait's fisheries management strategies and options. The following management actions were eventually taken:

1) Implementation of effort limitation, identified originally in 1981, confirmed in 1984, and reconfirmed in 1985, was delayed in 1986 and 1987 while the results were verified by Gulland[4] and Gulland (1989) who confirmed the potentially beneficial effects of effort reduction. Eventually, a reduction of effort was accepted in 1987, to about 5,000–6,000 days per year.

2) The delay in opening the fishery was confirmed but modified in detail. Opening on 1 September instead of 1 October maximized the benefit from increasing the mean size at capture (Gulland, 1989) but eliminated most of the potential for protecting the autumn spawners.

3) The two-stock management policy was discontinued, causing a definite economic loss to the *M. affinis* fishery of about US$1,000,000/year on average, which could have been harvested successfully (Mathews, 1989). This decision was made because of the impossibility of controlling the landings of *M. affinis* from artisanal boats during the closed season for *P. semisulcatus*, and the difficulty experienced in allowing industrial boats to fish while preventing artisanal boats from doing so.

4) The buy-back policy was delayed indefinitely or rejected because of its cost (estimated at about $3,000,000; Mathews et al., 1986).

Policy Effects

Background

In October 1987 the military/security situation imposed a night curfew on fishing which was effectively confined to Kuwait Bay and a narrow coastal zone near the Kuwait shore about 10 miles wide until the end of the Iraq-Iran war in late 1988 (Siddeek et al., 1991; Mathews[5]).

In November 1987 the ninth annual (occasionally twice yearly) "Shrimp and Finfisheries Management Workshop," uniting senior management personnel, fishing entrepreneurs, and scientists (e.g., Mathews, 1986b) was held. It was known that the security measures being enforced would markedly reduce the total effort that the combined fleets could expend. Therefore, a reduction to about 5,000 days per year was inevitable. Because of this, a much longer fishing season (until April) was allowed compared with previous years. The question of whether it was desirable to reduce the effort to around 5,000 days was never seriously discussed as no alternative was possible. Opposition by

[4] Gulland, J. 1987. Unpublished manuscript not available at KISR since the Iraq-Kuwait war.

[5] Mathews, C. P. Personal observations and discussions with fishermen.

fishing entrepreneurs to the large effort reduction recommended by scientists and endorsed by the managers of the fishery, which had been very vigorous and effective, was dropped.

Effects on Catch Rates

Shrimp landings in 1988–89 increased dramatically by about 300% (from 1,697 t to 5,023 t of *P. semisulcatus*). This led to a very sharp increase in profitability: 958 kg/standard boat/day of whole fresh shrimp (composed mostly of very high value *P. semisulcatus*), compared with a very much lower amount in earlier years (e.g., 237 kg/boat/day in the previous year, 85.9 kg/boat/day in 1985–86, and 73.9 kg/boat/day in 1984–85). Figure 7 shows these changes in *P. semisulcatus* catch rates.

Effects on Recruitment and Behavior

It is unlikely that landings were increased solely by reduction in effort. The surplus production and dynamic pool models (Fig. 2, 3) both predicted that total landings would not increase markedly even if effort were to be reduced substantially. It may therefore be argued (e.g., Siddeek et al., 1991) that a marked increase in recruitment must have taken place. Figure 6 can be interpreted to imply that a reduction in effort would lead to an increase in recruitment, and so to an increase in landings. This increase could have been caused partly or entirely by an increase in spawning stock. Figure 5 also shows the latest data for the spawning biomass index, and suggests that, for a decrease in effort to about 5,000 days per year, there would have been an increase in spawning index from about 150 kg/standard boat/day at the end of the fishing season (at an effort of about 7,000–10,000 days/year) in 1986–87 and 1987–88, to about 200 kg/day in 1988–89. The remaining increase (from about 200 kg/day to about 359 kg/day) (Fig. 4) could therefore be due to a change in recruitment (a more rigorous analysis is not possible because of some inconsistencies between some data points given by Siddeek et al. (1991) and Morgan (1989); e.g., 1981–82 spawning biomass is given as 305 kg/day by the former and is much lower in Morgan (1989), e.g., Figure 5). No unified data base was established (see below).

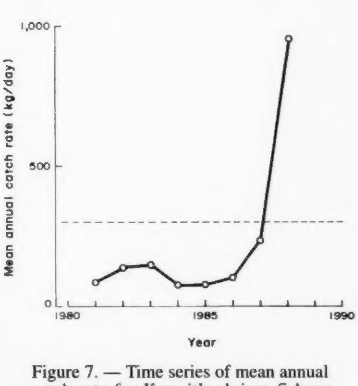

Figure 7. — Time series of mean annual catch rate for Kuwait's shrimp fishery (kg/day's industrial fishing). Calculated from data in Siddeek et al. (1991).

An alternative explanation for the increase in landings is possible: Penn (discussion in Farmer, 1981) and Penn (1984) suggested that *P. semisulcatus* may have formed large schools which would have been very much more vulnerable to fishing (and would provide much higher catchabilities) than would any *P. semisulcatus* caught while in a more dispersed, demersal phase. He drew particular attention to the difficulty in applying catch and effort models to Arabian Gulf data, should schooling have occurred in earlier years (e.g., the late 1960's) characterized by high catch rates. Hamdan et al. (1982) documented the incidence of exceptionally large catches of penaeid shrimp from both anecdotal experience and from scrutiny of catch data on KISR's RV *Asmak 4*, and concluded that it was likely that schooling occurred in *P. semisulcatus* at low effort levels. It is not clear what causes the change from schooling to demersal phases, but the cause may be related to interference by fishing at fairly low effort levels and the effects that this may have on the behavior of the shrimp. It would appear to be a stepwise effect rather than an effect that is proportional to effort.

Both Morgan's (1989) recruitment index and the spawning biomass indices are in fact simple catch transformations. The recruitment index consists of the annual (or other period) catch divided by *Y'/R* at the size at first capture, assuming that L_∞, *K*, *Lc*, and *M* (von Bertalanffy growth parameters, size at first capture, and natural mortality) are constant. Mathews and Samuel (1991) suggested that, contrary to this assumption, *M* may have varied substantially over the study period. The spawning index consists of the mean monthly *C/E* (in kg/standard boat/day for the 1- to 2-month period at the end of the closed season, immediately prior to the opening of the fishery). If a behavioral change of the type suggested by Penn (1984) and Hamdan el al. (1982) occurred, it would have increased the recruitment and spawning indices used by Morgan (1989) and Siddeek et al. (1991) without any real increase in numbers of recruits having taken place. Siddeek et al. (1991) suggested that the increased spawning index provided evidence that an improvement in recruitment had occurred, but there is in fact no proof of this.

Environmental Effects on *P. semisulcatus*

Since the increased catch rates (and their derived indices of recruitment and spawning) in 1988–89 and 1989–90 cannot provide any basis for proving the existence of an increase in recruitment, the hypothesis that an environmental change caused improvement becomes speculative. It is currently unproved and untestable. So is the suggestion that behavioral changes actually caused schooling, although this has been shown to occur in other penaeid species elsewhere and probably occurred in the Gulf stocks of *P. semisulcatus* in the past.

Environmental Effects on *M. affinis*

The evidence for an environmental cause of the fall in *M. affinis* catches (Siddeek et al., 1991) is lacking. No salinity or other oceanographic data for Kuwait waters have been provided to test this idea objectively.

Mathews' (1989) study of the biology and management of the *M. affinis* stocks shared by Iraq and Kuwait suggested that the migration of *M. affinis* postlarval and/or juvenile stages in Au-

gust and September to the Iraqi marshes was inhibited by the fast flow of the Shatt Al Arab at this time. The slower current velocities in winter were less likely to do this for the spring recruits, which did reach the brackish water marshes and grew to the size at which sexual maturation occurs. In the Iraqi marshes, salinities of about 6‰ occurred and were hypothesized to be too low for sexual maturation. The large shrimp migrated from the marshes back to the spawning grounds to mature sexually and to spawn. The lowest salinities observed in northern Kuwait waters during oceanographic surveys (e.g., Lee, 1984) reported a minimum of 36‰ near the mouth of the Shatt Al Arab, and there is no evidence that salinities ever fell to lower levels on the Bubiyan fishing grounds (Fig. 1, area 3, northern section). Some very low salinities were reported (about 32‰, Mathews[6]) in the mouth of the Shatt Al Arab but were of very short duration and have not been confirmed.

Mathews (1982a, 1989) did not identify the exact spawning grounds of *M. affinis,* but he did show (1982b, 1991) that mostly very small and very abundant *M. affinis* occur on the Bubiyan fishing ground (Fig. 1, area 3), whereas mostly very large, sexually mature *M. affinis* occur in Kuwait Bay (Fig. 1, area 1). It is likely that Kuwait Bay and Rixa are important spawning grounds and that the northern Bubiyan area (most susceptible to influence by Shatt Al Arab waters) is a major nursery area for large juveniles. In a series of descriptions of the oceanography of Kuwait waters, Lee (1984) showed (contrary to Mathews et al., 1980; Mathews et al., 1982) that the salinity and chemical composition of Kuwait Bay waters was not influenced by the inflow of Shatt Al Arab water to the Gulf through the very shallow gap between Sabiyah and Failakka Island. Therefore incursions of lower salinity waters from the Shatt al Arab need to enter the areas south of Failakka Island and penetrate through the mouth of Kuwait Bay if they are to affect spawning. Shatt Al Arab waters rarely if ever reach this far, and the marked changes in salinity needed to impact spawning have not been observed in Kuwait Bay or Rixa. Therefore the Kuwait Bay and Rixa *M. affinis* populations would probably not be affected by the postulated environmental changes (Siddeek et al., 1991), even if such changes were strong enough to reduce spawning on the Bubiyan grounds (where most of the *M. affinis* are small and sexually immature). There is no evidence that the salinities of 36‰ and above characteristic of the Bubiyan grounds would increase mortality of the juvenile *M. affinis* living there prior to migration to the spawning grounds, nor that they would inhibit spawning of any mature *M. affinis* that occur there.

It is well known that the fishing companies in Kuwait usually chose a strategy of targeting *P. semisulcatus* whenever possible (e.g., Mathews, 1984) because of the higher price for any given commercial size grade and the much higher sizes usually obtained for this species. *M. affinis* was usually fished only when *P. semisulcatus* was unavailable or when *P. semisulcatus* catch rates were very low. The very low landings of *M. affinis* (90 t) reported by Siddeek et al. (1991) are therefore consistent with the exceptionally high catches of *P. semisulcatus.* With only 5,243 days fishing in 1988–89, there would have been no spare effort to fish the *M. affinis* stock. Without any indication of the effort distribution of the artisanal and research vessel effort in 1988–89, and without data on the inflow of the Shatt Al Arab (usually kept as a military secret by Iraq) compared with that in previous years, there is no way to test the hypothesis of environmental effects on the northern Gulf prawn stocks.

Discussion

Hindcasting and the Usefulness of Simple Bioeconomic Analysis

The effort limitation policy finally implemented in Kuwait's trawl fishery in 1987–88 was in fact identified as early as 1981. An unpublished study on the bioeconomics of Kuwait's prawn fishery by Mathews and Burgess[7] (who amplified the analysis of Mathews and Samuel, 1991) showed that the cost of not following that strategy from 1981 to 1985 was about KD6, 500,000 (i.e., about $US23,000,000) for a fishery valued at about $US5,000,000 to $US6,000,000/year. The fishery actually experienced a small net loss instead of a significant profit. Neither the scientists nor the managers and entrepreneurs involved had sufficient confidence in the results to apply them in 1981. The scientists decided in about 1985–86 that the new strategy was feasible. A modified effort limitation policy was not accepted by the fisheries managers until 1987.

Simple bioeconomic analyses appear to be more powerful than biologists or managers believe, and their results should be treated with less skepticism and more respect. Nevertheless, the delay in accepting an effort limitation policy was reasonable and acceptable by current standards of the scientific evidence needed to justify strong management measures.

Therefore, 1) research should focus on the usefulness of simple bioeconomic models as tools for managing fisheries in developing countries: These models may be much more powerful than many suspect, and their results may usefully be applied at an earlier stage than is usually the case. And, 2) scientists and managers should be more aggressive in seeking to apply the results of bioeconomic analyses.

Problems in Implementing New Fisheries Management Strategies

Kuwait has traditionally tended to choose rather conservative, perhaps environmentally aware, policies for managing its fisheries. On occasion, concern for the well being of the stocks has been used to justify a decreased effort when even environmentally aware scientists recommended an increased effort. Kuwait also has a well developed structure for identifying management options for its fisheries, and it has the resources to fund research and management.

[6] Unpublished data no longer available from KISR since the war.

[7] Mathews, C. P., and T. P. Burgess. 1988. The bioeconomic basis for the management of Kuwait's fisheries. Unpubl. manuscr., 76 p., unavailable at KISR since the war.

Nevertheless, the recovery of Kuwait's shrimp fisheries documented by Siddeek et al. (1991) was not due to any major reduction in effort imposed by the government. The policy to reduce effort by about 50–70% identified in 1984 and 1985 (and confirmed in 1986), was not implemented in 1987 because there was a decision to discard the suggested buy-back/buy-out policy which would have motivated less efficient fishermen to leave the fishery. Without this motivation, it was impossible to convince fishermen to withdraw because they would have had no alternative use for their vessels.

In 1988, effort was indeed reduced drastically but it is unlikely that this could have been achieved without the pressure for security imposed by the Iraq-Iran war. Therefore, it is reasonable to conclude that only a major war persuaded government and industry to reduce effort sufficiently to bring about benefits anticipated by scientists.

Despite the inability to enforce the chosen policy of effort reduction, Kuwait had all the monetary and scientific resources to enable it to manage the fishery in the most environmentally friendly and economic manner. Perhaps, therefore, it is also reasonable to conclude that no other developing country is likely to be able to do this better. Indeed, in highly developed areas such as northern Europe, all the fisheries research carried out before World War II failed to lead to major improvements in the North Sea stocks of finfish. Yet Beverton and Holt (1957) documented major improvements in the stock condition of some North Sea finfish stocks due to the cessation of fishing in World War II (1939–45) which were slowly dissipated due to uncontrolled effort expenditures in the 1950's.

The Kuwaiti experience is not unique, and shows that even the establishment of high quality research and management mechanisms and procedures does not by itself enable the implementation of any management measure that requires a major departure from the established bioeconomic equilibrium. In Kuwait, effort levels in the trawl fishery were established by inappropriate management policies in the early 1960's when high catch rates attracted heavy overinvestment in the fishery (Mathews et al., 1986). By the early 1970's, companies which faced uneconomic catch rates amalgamated or withdrew from the fishery, but the high effort levels were never reduced by government action until the war imposed much lower effort levels on government and industry.

It is reasonable to ask whether fisheries scientists can, under the current governmental/research/industry/exploitation models, ever succeed in doing more than fine tuning an existing strategy. Perhaps it is possible to identify strategies for radically improving a fishery, while it is still impossible to implement such strategies. If true, this may be because of the different time frames in which scientists (who may think of the indefinite exploitation of a stock) and managers and entrepreneurs (who may live in a 1- to 2-year time frame) are locked into. It is usually managers, often highly responsive to industry, who set long-term research and management targets.

Patterson (1991) suggested that "... the real management goal in most fisheries is a complex maximization: The point of least political pressure on the fisheries manager. In most situations this is achieved by maximizing access at the expense of the profitability of participants." If true, this will usually lead to harvesting stocks at very high effort levels and low biomasses, especially at low sexually mature biomass (e.g., Mathews 1991). In practice this would often lead to ignoring advice aimed towards conserving stocks subjected to either recruitment or biomass overfishing. In a world where most stocks are heavily fished or overfished, this must imply the effective rejection of most fisheries management advice.

If Patterson's analysis is correct, there is a need to identify some new way of making fisheries management decisions. Some key criteria could be to:

1) Include for each stock legal requirements that sufficient spawning biomass be maintained (e.g., using general criteria developed by Goodyear, 1989, for temperate fish, and by Mathews, 1991, for tropical fish and prawns), or adopt some other strategy aimed at avoiding a recruitment collapse. This policy is likely to maintain economically viable populations and fisheries indefinitely, and would protect fisheries managers from the pressures identified by Patterson (1991). This type of policy has been used successfully in the California current area (e.g., Parrish and MacCall, 1978).

2) Change the common access laws and customs for all fisheries so that a single organization is the owner or the effective exploiter, therefore allowing the exploiter to aim for maximum net profit without losing profit to other entrants. Such a policy could be equitable if combined with a system of periodic bidding for the rights to fish, thus dispersing the economic rent and allowing the principle that anyone may attempt to enter a fishery.

3) Attempt to carry out the kind of ecosystem studies, e.g, ECOPATH based (Christensen and Pauly, In press; Mathews, In press), that can provide the means of describing quantitatively the structure of, and the fisheries based on, a particular marine ecosystem. Such models may eventually allow comparison of both real and simulated "before" and "after" scenarios for whole ecosystems (including the fisheries they support) that will provide the means of managing fisheries more easily than before, and will provide the heuristic tools needed to facilitate communication between managers and scientists.

It is clear that the first of these suggestions requires a scientific consensus that has not yet been achieved, and that the second would require a political change and consensus that is even more unlikely to be achieved in the near future.

It is equally clear that adoption of the third alternative is not immediately feasible (some may even argue it is not desirable), and in any case it would result in the abandonment of the possibility of managing fisheries now when the technical basis for doing so is already available for many stocks but is not being applied. These are questions that should cause serious concern to all managers, scientists, and governmental agencies involved in living resource

management, and not only in developing countries.

Acknowledgments

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Trade and Management: Exclusive Economic Zones and the Changing Japanese Surimi Market

JOHN T. SPROUL and LEWIS E. QUEIROLO

Introduction

Japan has traditionally enjoyed virtual self-sufficiency in the supply of seafood to its domestic markets. Yet, in recent decades, Japanese suppliers have become increasingly dependent upon imports to meet consumer demand for many of these fish products. In 1970, for example, Japan was virtually 100% self-sufficient in seafood production and supply. By 1988, however, according to U.N. Food and Agriculture Organization data, nearly one-fourth of Japan's domestic seafood supply was derived from imports (Table 1). Indeed, by the late 1980's and early 1990's, seafood was among the few areas of international commerce in which Japan registered a "trade deficit."

ABSTRACT— The United States' increasing competitive advantage in international seafood trade in Alaska walleye pollock, Theragra chalcogramma, *has contributed to higher prices for surimi-based goods and structural changes in seafood production and trade in Japan. The objectives of this analytical investigation include: 1) Evaluation of the role reversal of Japan and the United States in international seafood trade and 2) quantification of the impact of rising prices of frozen surimi on household consumption of surimi-based foods in Japan. This study documents Japan's regression from "seafood self-sufficiency" to increasing dependence on imported products and raw materials. In particular, Japan's growing dependence on American fishermen and seafood producers is described.*

Surimi production by the United States, and its emerging dominance over Japanese sources of supply, are especially significant. Results of the analysis suggest that Japanese consumer demand for surimi-based foodstuffs correlates directly with "competitive" food prices, e.g., pork, chicken, and beef, and inversely with personal income. Also revealed is how rising household income and relative price shifts among competing animal protein sources in the Japanese diet have contributed to declining household consumption of surimi-based foods, specifically, and a shift away from seafoods in favor of beef, in general.

The linkages between, for example, Japanese domestic seafood production and consumption, international trade in marine products, and resource management decisions in the U.S. EEZ present a picture of a changing global marketplace. Increasingly, actions in one arena will have perhaps profound implications in the others.

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Japan's Evolving Role in World Fisheries Trade

With the U.N. Convention on the Law of the Sea, most of the world's coastal nations (which had not formerly and unilaterally extended management jurisdiction over adjacent waters) instituted new resource management regimes in connection with the establishment of maritime Exclusive Economic Zones (EEZ). These regulatory changes have directly contributed to a fundamental shift in the relative status of the world's coastal and distant-water fishing nations (Queirolo and Johnston, 1992).

Japan, historically among the largest distant-water fishing powers in the world, was, as a result, profoundly impacted by this new ocean management

Table 1. — Japan's rate of self-sufficiency by major crops and other food groupings, 1960–88.[1]

	Percent self-sufficiency								
Item	1960	1965	1970	1975	1980	1985	1986	1987	1988
Crop									
Rice	102	95	106	110	100	107	108	100	100
Wheat	39	28	9	4	10	14	14	14	17
Potatoes	100	100	100	99	96	96	96	94	93
Starch	76	67	41	24	21	19	20	18	15
Pulses	44	25	13	9	7	8	8	9	8
Vegetables	100	100	99	99	97	95	95	94	91
Fruits	100	90	84	84	81	77	74	74	57
Meat	91	90	89	77	81	81	78	76	73
Beef	96	95	90	81	72	72	69	64	58
Pork	96	100	98	86	87	86	82	80	77
Eggs	101	100	97	97	98	98	97	99	98
Milk products	89	86	89	81	82	85	82	78	76
Fish	111	110	108	100	97	86	86	82	80
Seaweeds	92	88	91	96	74	74	76	72	76
Sugar	18	31	22	15	27	33	34	34	34
Fats and oils	42	31	22	23	29	32	32	30	33
Other groupings									
Caloric supply	79	73	60	54	53	52	51	49	49
Food grains	89	80	74	69	69	69	69	68	68
Grains	82	62	46	40	33	31	31	30	30
Farm products	91	86	81	77	75	74	73	71	70
Fishery products	113	112	104	92	90	79	84	78	78
Total food	98	94	88	82	80	76	77	74	72

[1] Source: MAFF, Food Balance Sheet; Fujita, 1991.

strategy. Over a very short period of time, Japan's status in the world seafood market changed from a "net-exporter" of fishery products, to that of a "net-importer," dependent on external supplies to meet domestic demand.

Prior to the middle 1970's, Japan consistently reported annual catches and seafood exports which ranked at, or very near, the top among all nations. Likewise, the value of these catches and exports ranked number one among all reporting nations, over this period.

Over roughly the same interval of time, Japan ranked a relatively distant third, behind the United States and the Federal Republic of Germany, respectively, in terms of "volume of fishery imports," despite the very much greater role of seafood in the daily diet of the Japanese consumer.[1]

Beginning in 1982, and in each year thereafter, however, Japan surpassed the U.S. as the world's leading seafood importing nation, on the basis of product volume (1977 on the basis of value) (FAO, 1970–90). By 1989, Japan imported seafood valued at over US$10 billion, while U.S. imports were valued at less than US$6 billion (Fig. 1). In like fashion, since 1978, the United States has repeatedly outpaced Japan as the leading seafood exporter (on the basis of value) marking the beginning of Japan's dependence on U.S. seafood suppliers and the reversal of their respective roles in the world seafood marketplace (Fig. 2). Such dependency constitutes a critical juncture in the history of a nation that maintains a population whose per capita annual consumption of fish and fishery products reached a near world record of 72.7 kg in 1989, second only to Iceland (FAO, 1991).

[1] Japan ranked second, behind the United States, in terms of the value of imports over this period.

Figure 1. — Value of fishery products imported by Japan and the United States, 1970-89.

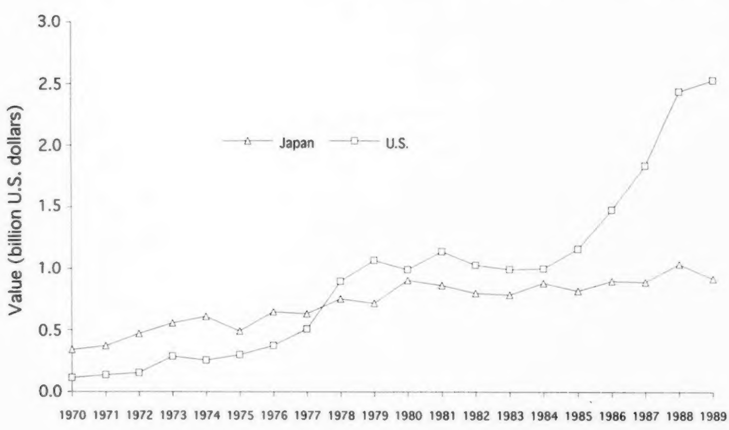

Figure 2. — Value of fishery products exported by Japan and the United States, 1970-89.

With the increasing trend towards "westernization" of the Japanese culture, the contribution of seafood to the average Japanese diet is decreasing. Nonetheless, seafood consumption remains extremely high relative to the rest of the world. For example, between 1961 and 1989, the "fish-to-animal protein" ratio in the average Japanese diet dropped from 67.9% to 50.6%. Over the same period in the United States, this ratio rose slightly from 4.6% to 6.4%.

In addition, Japan's role as a supplier of seafood in the world marketplace has been significantly altered. From a supplier of high-volume/high-valued seafood, such as fresh and fresh-frozen food products, Japan has become primarily an exporter of relatively low-valued seafood commodities, such as fish meal, oils, and soluble fats (Sproul, 1992a). Canned seafood once accounted for a significant share of Japan's fishery exports. Yet, between 1970 and 1989, Japanese exports of canned fish products declined by more than 65%. Rising world prices for canned seafood, especially in the United States, to some extent sustained Japan's total seafood export value.

The Decision to Establish an EEZ

As suggested above, Exclusive Economic Zones, extending in most cases up to 200 n.mi. seaward from the coast of the declaratory country, radically restructured the world's ocean fisheries. In so doing, it simultaneously reordered international importer-exporter relationships by limiting resource access to the majority of the world's fishery resources on the basis of nationality.

By the mid–1970's, in the view of the U.S. Congress, certain stocks of fish in the oceans adjacent to the United States had been severely overexploited. At

least in part, this was believed to be a consequence of the rapid growth in fishing pressure and inadequate international management and conservation practices. The best scientific information available suggested that some of these ocean stocks had reached a point where their very survival was in doubt, while many others appeared to be in serious danger of reaching the same degraded state.

Existing international fishery agreements were not preventing this destruction, nor were they mitigating the continued overfishing of these highly valued resources. Therefore, the U.S. Congress resolved to institute a national conservation and management program, extending over the United States' living marine resources to prevent further degradation and to provide for the rebuilding of overexploited stocks.

The Congress also envisioned a program that would faciliate the "domestic" development of fisheries that, at the time, were underutilized, or not utilized at all, by the U.S. industry. The clear intent was to assure that benefits from employment, food supply, and commerce deriving from these fisheries would accrue to U.S. citizens. The result was adoption of the Magnuson Fisheries Conservation and Management Act of 1976 (MFCMA or Act). And, after implementation of the MFCMA, foreign participation in virtually all northeastern Pacific and eastern Bering Sea fisheries was brought under U.S. jurisdiction, and most were dramatically curtailed.

In debating the Act, the U.S. Congress acknowledged that many coastal areas of the United States are historically dependent upon fishing and affiliated activities. The Congress further cited what it believed to be the adverse impact that massive foreign fishing fleets operating in waters adjacent to these communities had on them. Thus, in light of these findings, the Act was explicitly designed to promote domestic utilization of the fisheries resources of the EEZ, through displacement of foreign capacity and fishing activities.

To this end, a number of innovative management strategies were developed by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service, the agency principally charged with implementation of the Act. One important example was the "Fish and Chips" policy. "Fish and Chips" was first informally articulated in the late–1970's. Reportedly, the initial use of "Fish and Chips" in negotiations took place in May 1977, when U.S. representatives discussed foreign fisheries allocations in the newly established U.S. EEZ with representatives from Italy, Spain, the EEC, and Japan (Freese, 1985). Subsequently, the policy was in large degree institutionalized in the form of the American Fisheries Promotion Act of 1980 (AFPA). As Freese (1985:157) notes, "The American Fisheries Promotion Act of 1980 increased the number of criteria (upon which access to the U.S. EEZ was based) to include cooperation of foreign nations in removing trade barriers, the purchasing of joint-venture and shoreside processed products, the minimization of gear conflicts, and the transfer of technology."

As suggested, "Fish and Chips" was intended to facilitate the accelerated development of the U.S. domestic fishing industry. By rewarding foreign operators with temporary access to the U.S. EEZ, in return for fishing and processing technology transference, as well as access to overseas markets, these management policies contributed to the "Americanization" of fisheries for domestically underutilized species and greatly expanded participation by U.S. firms in the world fisheries marketplace. Under this management strategy, direct foreign access to fisheries allocations (referred to as TALFF) or cooperative operational allocations with U.S. fishermen (referred to as Joint-Venture Processing) were employed to reward cooperative foreign operators and punish uncooperative nations. While the "Fish and Chips" policy was not without its problems and critics, and was not always rigorously or consistently applied, it nonetheless reflected a management philosophy geared to the rapid growth of the U.S. domestic fishing and processing sectors, a philosophy consistent with the intent of the MFCMA.

By 1990, the fishery for Alaska or walleye pollock, *Theragra chalcogramma*, was totally "Americanized" (Fig. 3); and by 1991, as a result of the joint mandates of the MFCMA and AFPA, the entire North Pacific groundfish fisheries within U.S. waters were 100% "Americanized" (North Pacific Fishery Management Council, 1991), i.e., all direct foreign fishing activity within the North Pacific EEZ was eliminated, whether TALFF or Joint-Venture Processing. The impact of this policy on the northeastern Pacific pollock fishery and, in particular, the domestic Japanese food industry it supported, is the focus of the balance of this paper.

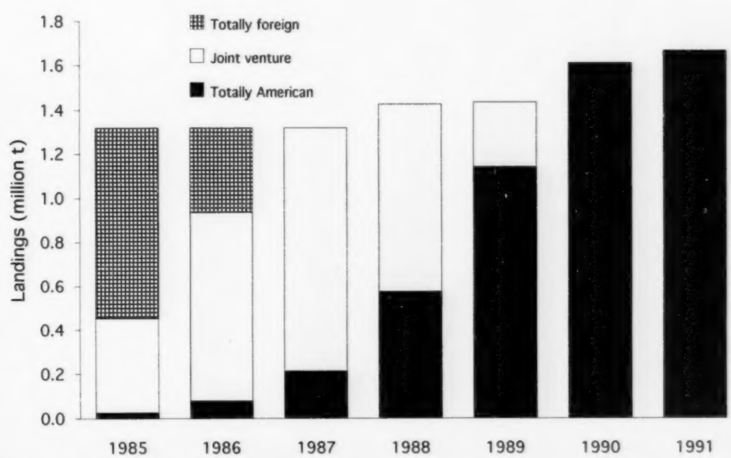

Figure 3. — Total landings of walleye pollock in the U.S. 200-mile EEZ, 1985-91.

An Historical Context

According to Chitwood (1969), "The first trawling for groundfish off Alaska by an Asian nation occurred in 1929 when Japanese vessels explored the eastern Bering Sea. This exploration led to the development of a full scale commercial fishery in the eastern Bering Sea in 1933." These early Bering Sea groundfish fisheries were reportedly producing fish oil and meal. By 1940, additional Japanese groundfish trawl fisheries in this area had begun to produce catches which were frozen for human consumption.

World War II forced the Japanese to curtail distant-water fisheries, including those in the northeastern Pacific and Bering Sea. By the middle 1950's, however, Japanese trawlers were once again harvesting walleye pollock, among other species, from these waters. During the early 1960's, the Japanese groundfish trawl fleet had expanded westward along the Aleutian chain and into the Gulf of Alaska.

This expansion was, in part, dependent upon a technological development made in early 1959 at the Hokkaido Fisheries Research Laboratory, Abashiri, Japan. Researchers there perfected a method of freezing processed minced fish meat which maintained both the chemical and textural integrity of the flesh. The resulting fish paste was referred to as surimi (Nishiya et al., 1961), and it is used to produce processed foods for human consumption.

Fresh surimi had long been the principal building block for a myriad of traditional Japanese foods using processed fish. However, until it was possible to produce a high quality frozen surimi, product storage, transportation, and shelf life were very limited. With the Hokkaido technological developments, demand for frozen surimi grew in Japan's food processing industry. In the 1960's, factory trawlers (ship-based frozen surimi plants) enabled Japan to dramatically increase exploitation of the previously underutilized North Pacific pollock resource. The fishery grew at an unprecedented rate, with Japanese commercial pollock catches increasing rapidly through the late 1960's and reaching a peak in 1972 of 1.6 million metric tons (t).

Following Japan's lead, several other nations began to harvest pollock from these waters (Table 2). These included distant-water fleets from the former U.S.S.R., the Republic of Korea, and, somewhat later, Taiwan, Poland, and the Federal Republic of Germany.

Walleye pollock is the primary species targeted by surimi producers in the North Pacific, with annual commercial catches, worldwide, reported to surpass 6,000,000 t (FAO, 1990). In the early 1970's, Japan's distant-water North Pacific trawl fleet, composed of factory trawlers and mothership operations, was the main domestic source supplying walleye pollock to the Japanese market (Fig. 4).

Japan's Neriseihin Market

Walleye pollock is the preferred species in the production of surimi (Table 3). Japanese processors of surimi-based foods (neriseihin) grew dramatically in number as did production capacity during the expansionary period of Japan's North Pacific distant-water trawl fleet. However, as management authority over North Pacific groundfish resources was claimed by the United States and Russia, this expanded surimi-dependent industry itself became increasingly reliant on imported surimi (Fig. 5).

Japan's National Surimi Association recently estimated annual world surimi production (Table 4). Their report revealed the increasing U.S. importance among major surimi producing nations. In just over 5 years (1985–91), Japan fell from the position of undisputed world surimi production leader to one of shared leadership with the United States.

Worldwide, the majority of walleye pollock harvesting capacity exists outside of Japan. In combination with the significant portion of surimi production occurring outside of Japan, apprehension within Japanese food processing industries that depend on adequate supplies of surimi at historically reasonable prices, intensified. These concerns were proven to be justified when, in 1991, Japan could not import sufficient quantities of surimi to compensate for its domestic production decline.

Besides greater amounts of American-produced surimi being exported to Korea, only a portion of which is reexported to Japan, poor landings of At-

Table 2. — Annual pollock catches in the eastern Bering Sea by foreign distant water fleets.

	Pollock catch (t)						
Year	Japan	USSR	ROK	Taiwan	Poland	FRG	Other
1964	174,792						
1965	230,551						
1966	261,648						
1967	550,362						
1968	700,981[1]		1,200[2]				
1969	830,494	27,295	5,000				
1970	1,231,145	20,420	5,000				
1971	1,513,923	219,840	10,000				
1972	1,651,438	213,896[3]	9,200				
1973	147,814	280,005	3,100				
1974	1,252,777	309,613	26,000				
1975	1,136,731	216,567	3,438				
1976	913,279	179,212	85,331				
1977	868,732	63,467	45,227	944			
1978	821,306	92,714	62,371	3,040			
1979	749,229	58,880	83,658	1,952	20,162		
1980	786,768	2,155	107,608	4,962	40,340	5,967	
1981	765,287		104,942	3,367	48,391	9,580	
1982	746,972		150,525	4,220		1,625	
1983	654,939		170,007			10,038	
1984	626,335	12,268	167,887		46,900	8,304	48
1985	584,484	1,504	160,735		22,696		
1986	256,178		76,313		3,616		1,043

[1] The Japanese also harvested small amounts of pollock from the Gulf of Alaska. From 1967 through 1975, for example, they reported catches ranging from 6 t to 30 t.

[2] Some trace amounts of pollock were reported from the Gulf of Alaska.

[3] The U.S.S.R. also reported landings of pollock in the Gulf of Alaska, although the amounts were quite small. Only trace amounts were reported before 1972. Between 1972 and 1975, catches ranged from 20 t to 38 t.

lantic cod, *Gadus morhua*, increased European demand for walleye pollock, in the form of fillets. Higher profitability from fillet sales encouraged American processors to reallocate portions of their catch from surimi production to fillets destined for the European market. The result was an overall decline in global surimi production and, more importantly to Japan, reduced amounts of surimi available for importation.

Japanese Demand vs. World Supply of Surimi

The growing presence of U.S.-produced surimi in the Japanese import market is significant. From 1986 to 1992, direct imports (not including joint-venture products) of U.S.-produced surimi rose from 1.5% to 28.2% of the Japanese market, peaking in 1990, when it accounted for 31.2% of total supply (Sproul, 1992b).

Japanese domestic demand for surimi has continued to exceed domestic supply. Through 1991, "high-quality" surimi imports received an increasingly higher market price. Traditionally, price differentiation is a function of quality. For surimi, quality distinction is primarily attributed to production conditions. Given the enzymatic and biochemical characteristics of pollock, once harvested, tissue quality diminishes rapidly (Ehira and Uchiyama, 1974; Lerk, et al., 1965; Ang and Hultin, 1991). The Japanese generally believe that, due to faster conversion from live fish to frozen surimi, factory ship operations produce higher quality surimi. Following this reasoning, Japanese importers categorize surimi into several grades, based partly on whether it was produced by at-sea or shore-based operations. The result is a multi-tiered, grade-dependent, hierarchy of the surimi product based on both real and perceived quality differences.[2]

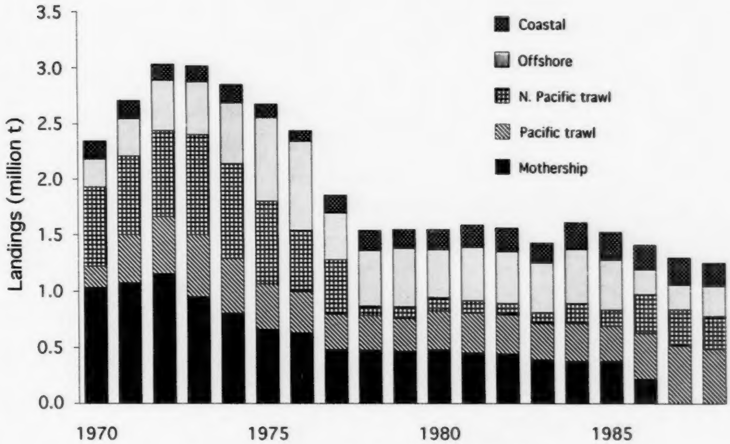

Figure 4. — Japanese landings of walleye pollock.

Table 3. — Production of surimi from principal fishes in Japan: 1975–89.[1]

		Production (t)				
Year	Total	Walleye[2] pollock	Sardine, mackerel	Atka mackerel	Horse mackerel	Other
1975	422,727	416,250		2,908	5	3,564
1976	462,738	453,154		6,361	10	3,213
1977	446,365	428,983		13,044	1	4,337
1978	381,132	369,057		5,669	1	6,405
1979	380,909	366,366		7,459	21	7,053
1980	374,244	355,147		10,353		8,744
1981	367,518	349,238	1,674	9,064		7,542
1982	383,928	366,915	2,234	7,629		7,150
1983	389,805	374,380	3,914	3,141		8,370
1984	425,829	401,571	8,983	3,875		11,300
1985	396,174	364,068	13,451	3,540		15,115
1986	352,349	308,957	13,168	4,451		25,773
1987	307,751	283,345	5,260	2,464		16,682
1988	291,704	267,513	4,471	5,286		14,434
1989	287,070	264,447	3,215	5,973		13,435
1990	241,000	196,000	I[3]	I	I	45,000
1991	211,000	166,000	I	I	I	45,000

[1] Source: Japan Fishery Products Distribution Statistics; 1990–91 values from Ministry of Agriculture, Forestry, and Fisheries, "Monthly Japanese Trade Report" - Ministry of Finance, as presented by All-Japan Kamaboko Makers Association at JETRO Surimi Forum, 1992, Tokyo.

[2] Includes fresh and frozen surimi processed at-sea or at land-based facility. J.V production excluded.

[3] I = included within "Other" category.

Note: Non-walleye pollock surimi is from land-based factories.

While the distinction has become less meaningful, the Japanese convention of distinguishing between "at-sea" and "shore-based" sources of pollock surimi will be retained for purposes of examining trends in product supply and price for the balance of this paper.

Surimi Price Trends

Surimi prices in Japan have increased dramatically since 1976 for all three principal grades of surimi (Fig. 6). In part, due to speculation and uncertainty about future supply, surimi prices rose dramatically in 1977. The annual average price for high grade at-sea surimi remained high through 1980. However, in 1981, a significant downward price adjustment occurred, due partly to improved confidence in future product availability resulting from joint-venture

[2] Technological advances in surimi production, as well as improvements in fish handling and transportation of catch, have reportedly narrowed the perceived quality gap between at-sea and shore-based surimi. Indeed, at the time of this writing, shore-based processors operating in the Bering Sea and Gulf of Alaska produce surimi of all three principal grades, including "SA" or highest grade product. Likewise, at-sea processors do not produce a single, high-grade product, but instead respond to market signals and changing fish quality to produce the most appropriate grade of surimi at any given time. It would, therefore, be inappropriate to place too great an emphasis on the distinction between at-sea and shore-based product.

arrangements with U.S. catcher boats that remained firm throughout the early 1980's. From 1978 to 1990, prices for shore-based surimi remained relatively constant. Exceptions to this were the 1981 downward price adjustment previously described and the 1986 price peak associated with the dramatic appreciation in the Japanese yen.[3]

[3] The strong appreciation in the value of the Yen followed the Reagan-Nakasone 1985 Plaza Accord.

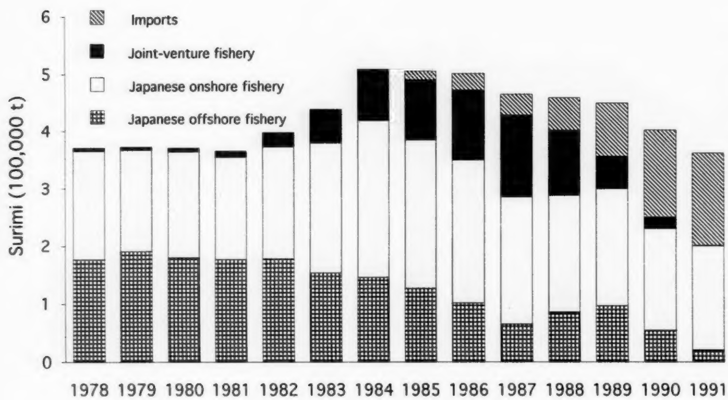

Figure 5. — Japan's sources of surimi.

Table 4. — World's major surimi producing nations,[1] 1985–91.

	Production (1,000 t)											
	Japan			U.S.A.			Korea	U.S.S.R.	Argentina	Thailand	
Year	S.B.[2]	L.B.[3]	S.T.[4]	S.B.	L.B.	S.T.	S.B.	S.B.	S.B.	L.B.	Total
1985	240	250	490			0	20			10	520
1986	240	200	440			0	20			20	480
1987	220	260	480		20	20	30			20	550
1988	240	220	460	20	40	60	30			30	580
1989	150	240	390	40	40	80	30		10	20	530
1990	80	200	280	120	50	170	20		10	20	500
1991	30	160	190	120	40	160	10	20	10	20	410

[1] J.V. production values are allocated to producing nations not landing nations. Source: Japan National Surimi Association.
[2] S.B. is production from Sea-Based vessels
[3] L.B. is production from Land-Based locations.
[4] S.T. is Sub-Total.

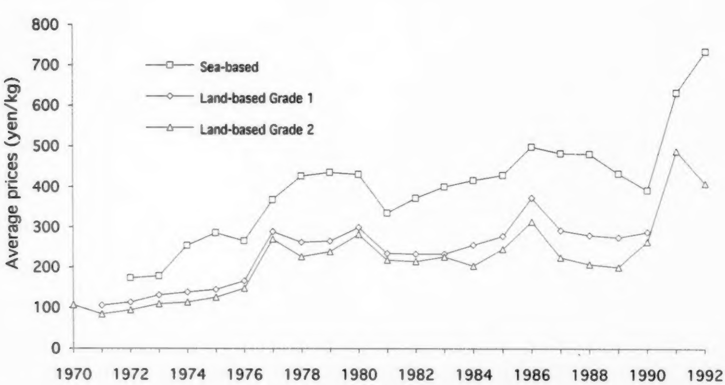

Figure 6. — Average surimi prices in Japan.

However, between January and December 1991, prices of at-sea and shore-based surimi increased 100% and 50%, respectively (Fig. 7). Several factors contributed to this dramatic surge in Japan. As previously noted, domestic demand outpaced available surimi supply in Japan during 1990. In addition, by that same year, walleye pollock joint-venture operations had been phased out in the U.S. EEZ. To some extent, this caused the surimi industry in Japan to relapse temporarily into its 1977 apprehension over future supply. To exacerbate matters further, prices for walleye pollock fillets, relative to surimi, rose in late 1990 with the decline in the North Atlantic groundfish fishery (Freese, 1991). This economic climate of relatively high pollock surimi prices may well have been perpetuated by the announcement from Canada's Minister of Fisheries and Oceans of a 2-year moratorium on the northern Atlantic cod fishery effective June 1992 (World Fishing, 1992).

As a result, demand for walleye pollock fillets bid surimi prices up on the world market. Prices peaked in Japan in late 1991 when domestic production of surimi-based foods was in full-swing to meet high seasonal domestic consumer demand during December and January. Figure 7 reveals the dramatic rise in monthly surimi prices from late 1990 through 1991, as well as their tapering off again in early 1992. Restocking of low frozen surimi cold-storage inventories in Japan was prompted in the spring and summer of 1992 as prices began to ease (Fig. 8).

Japan's Changing Consumer Behavior

The Japanese have shifted from their traditional position of high rates of saving relative to personal consumption, to a "nation of consumers" (Emmott, 1989). This is a direct result of rising personal income and the elimination of tax-exempt status for personal savings in the late 1980's. Between 1975 and 1987, Japan's private sector net financial wealth-to-income ratio rose from 0.99% to 2.17%, while the saving ratio over the same time period fell from 22.8% to 15.1% (OECD, 1990).

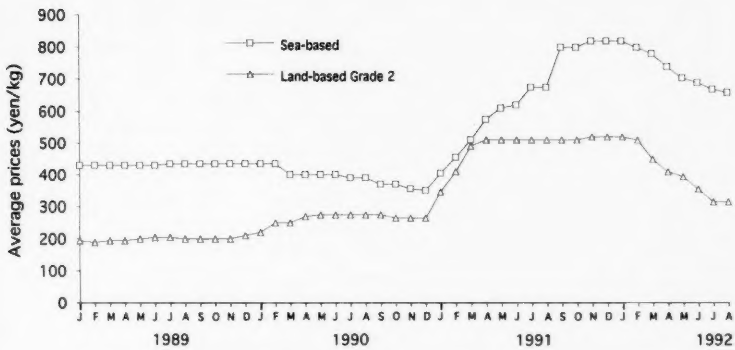

Figure 7. — Average monthly surimi prices in Japan, January 1990 to August 1992.

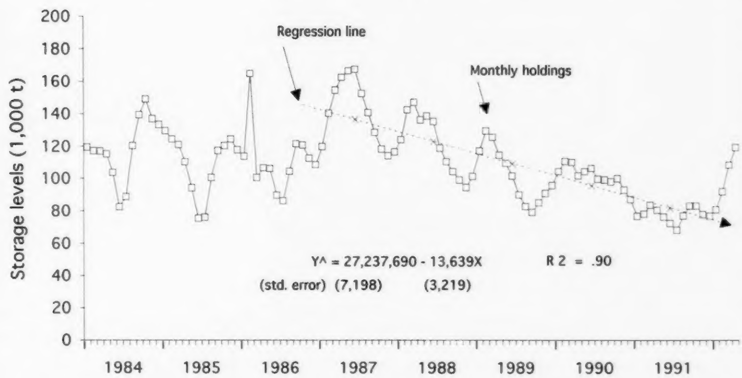

Figure 8. — Month-end levels of frozen surimi in cold storage in Japan, January 1984 to April 1992. Regression based on values from January 1987 to December 1991.

This economic prosperity has provided many Japanese consumers with opportunities that were otherwise unavailable at their previous level of expendable income. The Japanese domestic seafood market underwent transition as consumers became increasingly more selective as their personal wealth rose in the 1980's during the rapid growth of the national "bubble" economy.[4] Demand for high-valued fresh/frozen seafoods, now primarily import goods, grew. Generally, neriseihin foods would be among those processed food groups which Japanese consumers substituted for and moved away from.

Over the past decade, several factors have broadened the list of foods considered "acceptable" in the Japanese marketplace. These have encouraged diversity in consumption among seafoods and between competitive meat product forms. Among these influences are "price effects" resulting from nationalized EEZ fishing jurisdiction, "income effects" due to rising Japanese personal wages, and "taste effects" created by greater exposure through travel and exposure to nontraditional Japanese cultures and consumables.

Engel Curve Analysis

Trends in Japanese household consumption were investigated as a function of income, over time (1980 through 1990), using Engel curves to quantify consumption patterns of neriseihin and competitive protein sources, i.e., chicken, pork and beef.[5] Changes observed between Engel curves of these commodities, but during the same year, would reflect variations in the relative consumption of each food category within the home. The result provides a means of detecting consumption trends for specific food groups.

The Annual Report on the Family Income and Expenditure Survey provides household expenditure data on specific foods (SBMCAJ, 1991). The expenditure values for neriseihin, beef, chicken and pork were converted to consumption quantities by dividing them by their respective average annual price as calculated for each income category. Regression analysis was conducted on these quantities as a function of income, generating Engel curves for each food category for the years 1980, 1985, and 1990. Figure 9 A, B, and C combines Engel curves of each food for the years 1980, 1985, and 1990, respectively. These data thus give comparisons among the years in household consumption of these foods.

To help visualize the implications of these shifts specifically to the average household in Japan, a vertical line corresponding to average nominal household annual income is provided in Figure 9 A, B, C. Using this average household income level ($\overline{X}$) as a reference, the estimated quantities consumed at home (*Y^*) of each food group for the average household in Japan during 1980, 1985, and 1990, are quantified and presented in Table 5.

As hypothesized, the annual rate of change in household consumption of neriseihin dropped most significantly in Japan during the second half of the 1980's (also Table 5). This correlated with a time of dramatic yen appreciation that followed the 1985 Plaza Accord.[3] It created conditions that allowed previously expensive foreign produced

[4] This phrase is commonly used by the Japanese media to describe the rapid growth of Japan's national economy during the late 1980's.

[5] Engel curves are a means of quantifying shifts in consumption over time across and within income brackets. An Engel curve is a function relating the equilibrium quantity purchased of a commodity to the level of money income. The slope of the Engel curve at any given point indicates the income elasticity of demand for the good at that corresponding income level. Generally, income elasticities calculated for a particular good correspond to the average income level for the population under scrutiny. An Engel curve implicitly assumes constant prices for the time period evaluated.

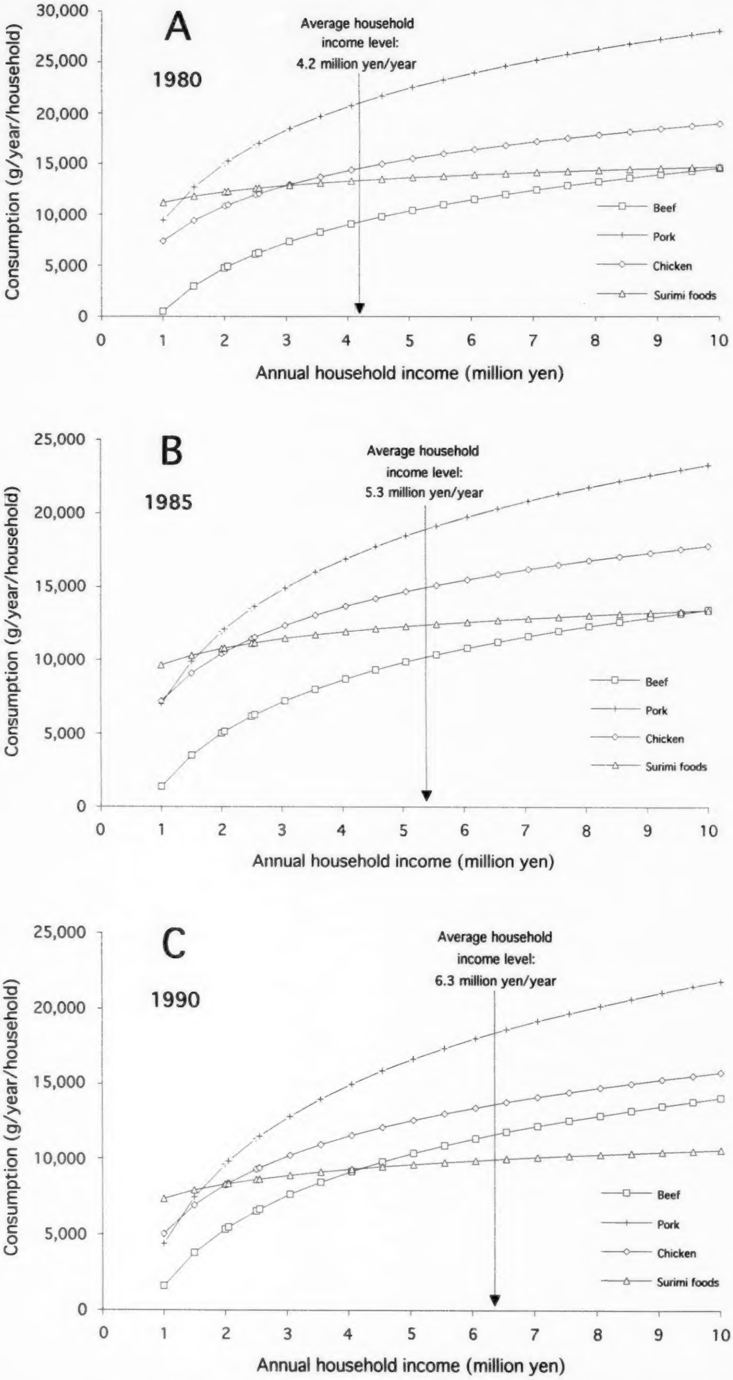

Figure 9. — Engel curves for Japanese household consumption of beef, pork, chicken, and neriseihin, collectively presented by year: A=1980, B=1985, and C=1990.

goods to appear increasingly more price competitive, relative to domestic products. This period proved especially devastating for neriseihin consumption, given its exacerbated problem of rising real prices.

These results confirm the evolving nature of the Japanese consumer's food preferences, as reflected in the retail marketplace. While the reasons for these changes are complex and numerous, we would argue that an important factor has been the increased dependence of Japan on "import" sources for many of its primary animal protein food stuffs, but particularly for seafoods. Had international fisheries management not so suddenly and broadly excluded Japan from directly accessing distant-water fisheries resources, the patterns of change within the Japanese market, cited above, may not have been so pronounced nor so rapid. The result may have been a more systematic and less disruptive adjustment to a changing world marketplace.

Summary

Over the past decade, significant shifts in consumption patterns have occurred within Japanese households, especially in terms of specific seafoods. These have occurred in part as a result of trends in the international marketplace and marine resource management regime. As a result, Japan's food industry is changing from being production-export oriented to consumption-import oriented.

In 1990, total value of all food imported by Japan exceeded US$31 billion (¥4.5 trillion). As anticipated, recent years have seen various food production industries in Japan experience dramatic restructuring. Japan's seafood industry has been especially hard hit by the onset of the 200-mile EEZ era. Shifts in relative commodity prices and annual personal income have contributed to influencing household consumption patterns in Japan. Changes occurring between 1980 and 1990 were quantified using Engel curve analysis. The relevance of this exercise was to present implications for seafood demand in Japan resulting from relative price shifts among fish products and close competi-

Table 5. — Estimated household consumption of pork, chicken, beef, and neriseihin within an average income household representative of 1980, 1985, and 1990.

	Consumption				
Food item	1980[1] (g/yr)	1985[2] (g/yr)	Annual rate of change: 1980–85 (%)	1990[3] (g/yr)	Annual rate of change: 1985–90 (%)
Pork	21,029	18,886	−2.2	18,299	−0.6
Chicken	14,529	14,937	+0.6	13,178	−2.5
Beef	9,275	10,162	+1.8	11,540	+2.6
Neriseihin	13,371	13,299	−0.1	9,937	−6.0

[1] based on annual average household income of ¥4,196,232;

[2] based on annual average household income of ¥5,338,152;

[3] based on annual average household income of ¥6,261,084; as reported in Annual Report on the Family Income and Expenditure Survey, 1991. Note: All figures calculated using respective Engel curve equations for each food at corresponding year.

tive animal protein sources. Disproportionally rapid price increases among specific marine products relative to competitive proteins can potentially occur from external fisheries management decisions made by government bodies endowed with authority over those resources.

Generally, the mandate of most international and national marine resource management authorities is to protect future biological viability of their fishery stocks. In the case of the Magnuson Act of 1976, socioeconomic criteria are also incorporated in an attempt to attain "optimum sustainable yield" (as contrasted with "maximum sustainable yield) from the resource (Federal Register, 1983). Implied in this concept is a degree of responsibility by managers to domestic interests utilizing the resource.

Therefore, to this end, the implications that U.S. management decisions have for Japanese household consumption via market effects might well be considered by decision makers. That is, when the management decisions undertaken by one government have such profoundly significant influences, both short- and long-term, on demand in a key world seafood market, these impacts should be explicitly assessed and appropriately weighted in the decision process. Certainly, the linkages between national and/or international fishery management institutions and domestic food policies among users of these important resources need more careful examination. How the concerns of the EEZ nations and those of traditional user nations can be jointly accommodated in the management decision process is a challenge which will confront all parties well into the 21st century.

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